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Morphometric Analyses of Recent Channel Changes on the Tanana River in the Vicinity of Fairbanks, Alaska

Charles M. Collins

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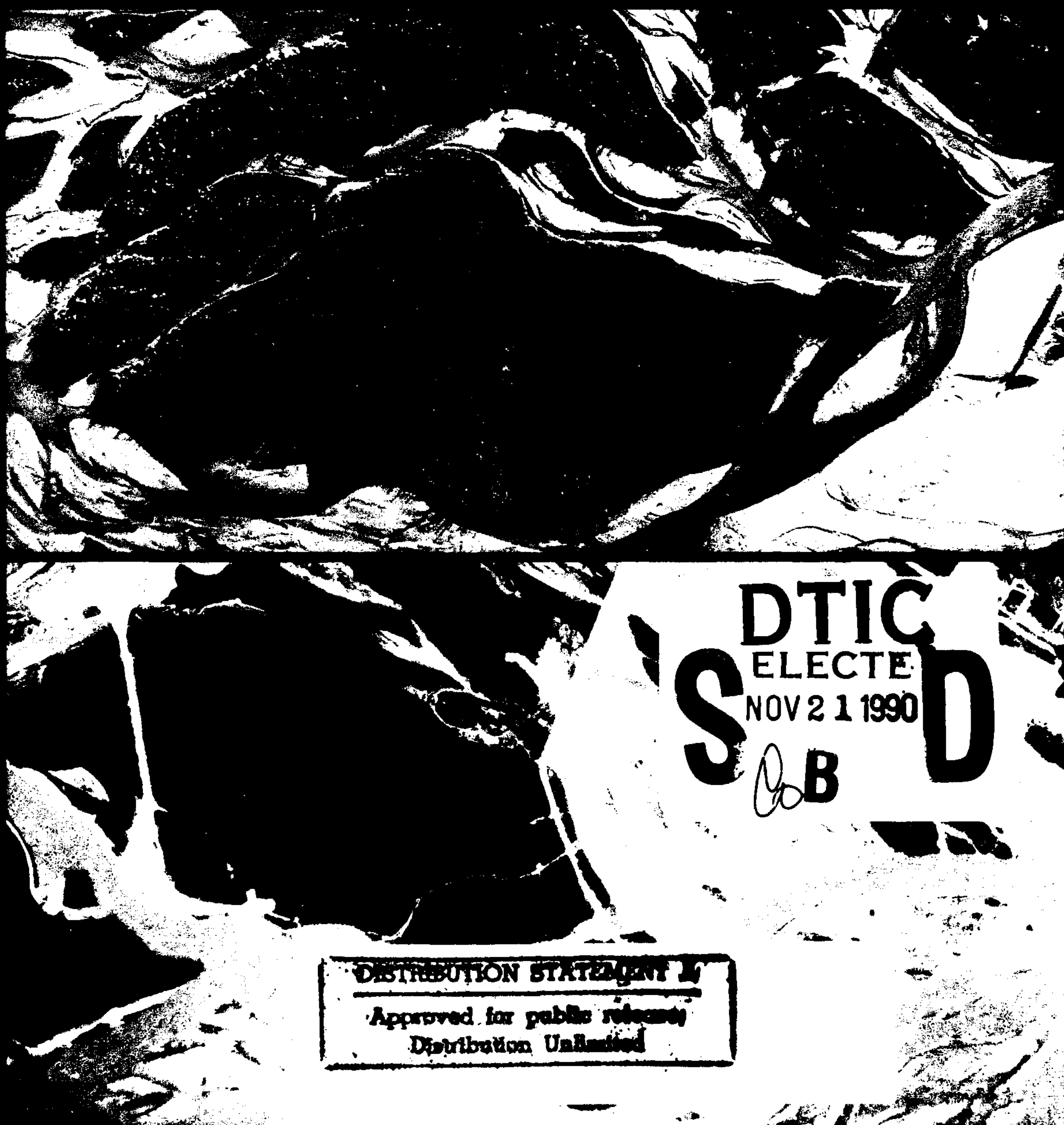

For conversion of SI metric units to U.S./British customary units of measurement consult ASTM Standard E380, Metric Practice Guide, *published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.*

Cover: Goose Island area of Tanana River in July 1938 (top) and June 1982. (Photos provided by U.S. Army Engineer District, Alaska.)

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U.S. Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

Morphometric Analyses of Recent Channel Changes on the Tanana River in the Vicinity of Fairbanks, Alaska

Charles M. Collins

June 1990

Prepared for
U.S. ARMY ENGINEER DISTRICT, ALASKA

PREFACE

This report was prepared by Charles M. Collins, Research Physical Scientist, of the Geological Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory, as one of the requirements for his M.S. degree from the Department of Geology, University of Alaska–Fairbanks. Funding for this research was primarily provided by the U.S. Army Engineer District, Alaska, under Intra-Army Order E-86-82-0005, *Tanana River Monitoring and Research Program*.

The author thanks the members of his thesis committee, Dr. James Beget (Committee Chairman), Dr. R. Keith Crowder, and Dr. Robert Carlson, and Dr. Robert Thorson, formerly of the University of Alaska, for early discussions about the subject of this report. In addition, thanks are expressed to Dr. Jerry Brown, now with the National Science Foundation, and Darryl Calkins of CRREL for their support over the years. Additional thanks are due to a number of people at CRREL who have worked with the author during various studies on the Tanana River, especially James Buska and Edward Chacho.

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INTRODUCTION

Traditional geomorphic and hydrologic studies of rivers have depended on field survey methods requiring extensive field data collection. Collection methods include channel cross-sectional surveys and water surface elevation measurements. These methods are both time-consuming and labor-intensive. Particularly on large river systems, the cost of measuring cross sections to adequately document river activities can become prohibitive.

Some data collection problems can be mitigated by the use of aerial photography and satellite imagery. The use of such tools for the collection of a wide variety of information on the environment has increased manyfold over the last decade. Use of remotely sensed data allows both rapid data collection over large areas and repetitive data collection over time. Through remote sensing techniques, rapid comparative analysis of geographic features over a large area are now possible. This is especially true with the introduction of new computer-driven image "change-analysis" systems that have recently become available.

Despite these technological innovations, a need continues to determine whether two-dimensional data collected from such comparative methods are sufficient to provide suitable information to evaluate impacts on complex three-dimensional systems such as rivers. This report uses applied geomorphologic methods to analyze changes over time in a stretch of the Tanana River near Fairbanks, Alaska, where obstruction of a major channel has caused changes in the river channel pattern. The data derived from the analysis of aerial photography are compared with other field data collected by more traditional survey methods.

The objectives of this report are threefold: 1) to determine the validity of use of two-dimensional data collected from aerial photographs to study changes in a large river system; 2) to determine the long-term bank erosion rates and channel changes in a stretch of the Tanana River using historical aerial photography, and 3) to determine the effects upon the river caused by construction of a large causeway and the length of time required for the river to return to an equilibrium state following construction completion.

A suitable site for such a study is located near Fairbanks, Alaska. Fairbanks was inundated by a major flood of the Chena River, a tributary of the Tanana, during August 1967. Total flood damage was estimated in excess of $84 million in the Fairbanks area (U.S. Army Corps of Engineers 1967, Childers et al. 1972). To prevent another such flood, a major flood control project was planned and constructed by the U.S. Army Corps of Engineers. Construction of the Fairbanks Flood Control Project on the Chena River and Tanana River in the vicinity of the city of Fairbanks began in 1975. While the major portions of the project were completed in 1981, minor portions remain uncompleted at this time.

The flood control project is composed of several components to prevent flooding of Fairbanks from both the Chena and the Tanana rivers. The major portion of the flood control project consists of an earth-fill dam and flood control gate system on the Chena River upstream of Fairbanks. Additional protection is provided to Fairbanks by a levee system extending 37 km along the north bank of the Tanana River between Fairbanks and the Tanana River. As part of the levee system, a number of protective dikes or groins have been constructed into the active river channel system to protect the levee from river erosion. Figure 1 shows the general setting of Fairbanks, the Tanana and Chena rivers, the components of the Fairbanks Flood Control Project, and the area of the Tanana River examined in this report.

In the Fairbanks area, the Tanana River undergoes a transition in channel pattern. It changes from a braided river with typically unstable bars and multiple channels upstream of Fairbanks to a pattern of several meandering main channels with stable vegetated islands downstream of Fairbanks. This transition zone of the river is an area of major interest, as it is the locale of the major construction associated with the Tanana Levee as part of the area-wide Fairbanks Flood Control Project.

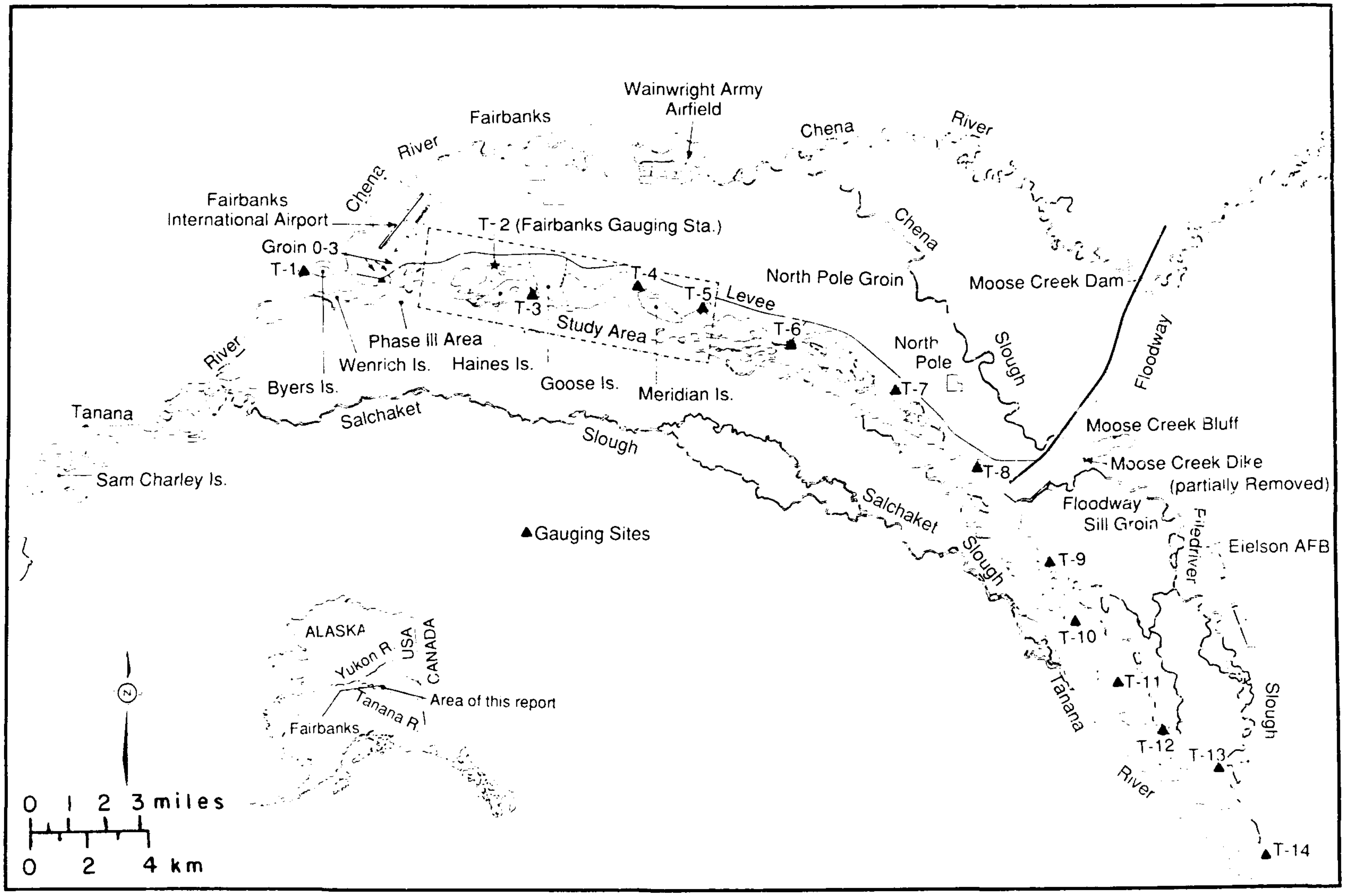


Figure 1. Location map.

Existing knowledge of large northern gravel-bedded rivers, especially the interaction between engineering structures and river processes, is limited. It is important to determine the impact that river engineering structures, such as groins, levees, and other river training structures, have upon natural river processes, in addition to understanding the effects of such processes as bank erosion, channel changes, and bar formation on the function and structural integrity of engineering structures. A better understanding of these interactions and relationships leads to an improved understanding of both the underlying basic river processes and design of engineering structures to control those processes.

Both physical and computer modeling have been used to design large river training structures and predict the effects of such structures on the complex interaction between river flow and sediment movement (e.g., Chang 1982). Computer modeling has been attempted on the Tanana River using cross-sectional data collected as part of the monitoring of the construction impacts upon a portion of Tanana River Levee near the mouth of the Chena River (Miles and Carlson 1984, Miles 1985). However, any modeling effort requires extensive field data to calibrate and refine the model. Collection of sufficient field data to validate a model is expensive and has often precluded the development of sufficiently accurate models for engineering design purposes. Use of aerial photography or other remotely sensed data allows rapid collection of additional information to partially remedy this data gap.

Many of the present criteria for river engineering structures require as limited an impact on river regime as possible. According to Nell and Galay (1967), there is a "...need to predict quantitatively the effects of engineering works... on the behavior of rivers... and growing recognition of the fact that interference with one feature of a river's constitution may upset a delicate balance and cause changes in many others." Reasons for limiting river regime interferences include not only avoidance of future engineering complications but also the mitigation of adverse impacts upon human usage of the river. River contractions resulting from construction of encroachments generally cause local scour of the bed and banks of rivers. The sediments derived from this erosion are often deposited in the immediate wider reach downstream, thus affecting the hydraulics of the system (Simons et al. 1978). Channelization and restricting of channel widths by river training structures along long stretches of a river have resulted in changes in the river regime, including accelerated lateral erosion wherever the river bank is not protected and scour erosion at the bases of protective dikes (Ritter 1979).

Increased erosion downstream caused by a river engineering structure is of major concern, as it affects other engineering structures downstream and damages adjoining land and property. The greater the intrusion into the river, the greater the temporary change in the river regime as it readjusts its channel. Thus determination of the time length of an impact from a major intrusion in the river and the corresponding extension downstream of any readjustment in the river regime allows improved planning and monitoring of impacts from future in-river construction of various river engineering structures.

LOCATION AND DESCRIPTION OF THE STUDY AREA

Location

The Tanana River Basin is located in east-central interior Alaska. It covers approximately 115,500 km^2, with all but 1200 km^2 of the basin located within Alaska, and is the largest tributary of the Yukon River. The city of Fairbanks is located on the Chena River, a tributary of the Tanana, approximately 10 km upstream of the confluence of the two rivers (Fig. 1).

Setting

The Tanana River Basin is bordered on the north by the Yukon–Tanana Uplands and on the south by the Alaska Range. However, a few tributaries, such as the Delta and Nenana rivers, have headwaters in the uplands to the south of the crest of the Alaska Range. The Tanana River flows through a broad alluvial valley consisting of two basins: the Northway–Tanacross Lowlands and the Tanana–Kuskokwim Lowlands (Wahrhaftig 1965, Anderson 1970).

Tributaries of the Tanana River are either glacially fed rivers draining to the north from the Alaska Range, or nonglacial streams draining to the south from the Yukon–Tanana Uplands. Eighty-five percent of the total annual discharge of the Tanana originates from streams draining the Alaska Range, with four major glacially fed tributaries, the Kantishna, Nenana, Nabesna, and Delta rivers, contributing 50% of the total basin discharge (Anderson 1970). The remaining 15% of the Tanana discharge originates in the Yukon–Tanana Uplands mainly from four main tributaries, the Salcha, Tolovana, Chena, and Goodpaster rivers (Anderson 1970). No glaciers are currently found in the uplands, although more than 20% of the uplands were glaciated during the Pleistocene (Weber 1986).

The Tanana River valley in the Fairbanks area, part of the Tanana–Kuskokwim Lowlands, is asymmetric in shape. It is bordered on the south by a large alluvial slope composed of coalesced low-gradient alluvial fans originating from the Alaska Range. To the north, the lowlands are bordered by the bedrock bluffs and rounded ridges of the Yukon–Tanana Uplands. The large alluvial slope has forced the main Tanana River channel to the north side of the valley, against the Uplands (Péwé and Reger 1983).

The Tanana valley in the Fairbanks area is filled with 90 to 250 m of Quaternary sediments and an unknown depth of Cenozoic sediments (Péwé 1965). Barnes (1961) reports 230 m of Quaternary sediments south of Fairbanks with the possibility of a maximum of 900 m of Quaternary material overlying a 7300-m Tertiary section at a gravity anomaly in the Minto area (located west of Fairbanks).

During the Delta Glaciation of the late Pleistocene, the increased discharge and sediment load from the glaciers of the Alaska Range caused the Tanana River and its tributaries to aggrade rapidly. Aggradation by the Tanana dammed the lower reaches of several valleys of the Yukon–Tanana Uplands; this action formed Harding, Birch, Chisholm and Quartz lakes (Blackwell 1965, Péwé 1975a). A period of downcutting by the Tanana followed the end of the Delta Glaciation, forming an upper terrace. During the Donnelly Glaciation, the Tanana River once again aggraded; the resulting floodplain was not built up as high as during the Delta Glaciation. Following the end of the Donnelly Glaciation, the Tanana cut down again, forming a second, lower terrace, whose age has been estimated at 10,000 years before present (B.P.) (Blackwell 1965). More recent work (Ager 1975, Weber et al. 1981, Péwé and Reger 1983) suggests that the ages of the dammed lakes may be younger than the Deltan age originally suggested by Blackwell (1965).

The recent geological history of the river is poorly known. Fluctuating periods of minor aggradation and downcutting are probable; these periods possibly correspond to minor Holocene climatic changes or alpine glaciations. Ager (1972) documented aggradation of the Tanana River floodplain at Healy Lake (located northeast of Delta Junction) by glacial outwash during the late Pleistocene; this action dammed the Healy River, impounding a large lake in the lower Healy Valley. During the Holocene the Donnelly-age lake was drained and its lacustrine deposits incised by the Healy River. In the Holocene, at the start of the Neoglacial, renewed aggradation of the Tanana River floodplain, minor in comparison with that associated with late Pleistocene glaciation, again dammed the Healy River forming the present day Healy Lake. In the Fairbanks area, dating of peat accumulations suggests that they began to form approximately 3500 years ago; these accumulations may reflect the change to the cooler, moister conditions of the Late Holocene Neoglacial interval (Hamilton and Robinson 1977, Hamilton et al. 1983).

Fernald (1965), through dating of organic material and volcanic ash, obtained data for alluvial–colluvial filling rates in the floodplain and lower tributary valleys in the upper Tanana River area. Accumulation of organic-bearing material began between 10,500 and 6000 years B.P.; greatest accumulation occurred around 6000 to 1900 years B.P. and minimal accumulations have occurred during the last 1500 to 2000 years (Fernald 1965). The average rate of accumulation has been about 45 cm per 1000 years (Fernald 1965). Although this is not direct evidence of the rate of aggradation of the Tanana River in the Fairbanks area, these data may be indicative of the overall equilibrium of the upper Tanana River system. New work at Fairbanks and downstream shows the river at approximately the current position for the last 1500 to 2500 years B.P.*

Climate

Selkregg (1974) includes a detailed discussion of the climate of the Tanana Basin. The Tanana Basin has a continental climate of long, cold winters and short, warm summers. The average annual temperature in Fairbanks is –3.5°C, with record extremes of 36°C and –52°C (NOAA 1982). Precipitation averages 25 to 56 cm of water equivalent per year over the basin with 76 to 150 cm of snow (Selkregg 1974). Upper tributary basins in the Alaska Range receive considerably more snow, with the maximum occurring at Summit (located on the Richardson Highway near the crest of the Alaska Range) with an average snowfall of 358 cm. Tributary basins from the Tanana Uplands, such as the Chena River Basin, also receive considerably more precipitation than lowland sites. The Chena Basin receives an annual average of 51.8 cm of water equivalent vs the 30.5 cm of water equivalent at Fairbanks (Santeford 1976).

Permafrost

The Tanana River basin is located entirely within the discontinuous permafrost zone. The distribution and thickness of the permafrost varies widely and is dependent on slope and aspect, vegetation, and soil type. Permafrost is absent on south-facing slopes, and beneath existing and recently abandoned river channels, sloughs, and lakes. Maximum permafrost depths reach 81 m in the Fairbanks area (Péwé and Bell 1975a, 1975b).

Development of permafrost in alluvial sediments is intimately related with the vegetation successional patterns in the floodplain (Viereck 1970). Older riverbank material, especially channel fill deposits containing fine-grained material, is often frozen (Péwé 1975b, Péwé and Bell 1975a, 1975b, Péwé et al. 1976). Whether the presence of permafrost inhibits or enhances bank erosion is unclear (Scott 1978, Lawson 1983). Using the numerous exploration drill logs available from the construction of the Tanana River Levee, Gatto (1984) tried

* J. Beget, University of Alaska, personal communication, 1988.

to correlate bank material, permafrost, and vegetation with potential erodibility based on past erosion rates of a stretch of the north (right) bank of the Tanana near Fairbanks, but he found no correlation based on the data available.

Vegetation

The regional vegetation of the Tanana Basin is characterized by stands of white spruce, which are found both on well-drained soils on low terraces of floodplains and on south-facing slopes. Black spruce, larch or tamarack, and low shrub bogs are found on poorly drained lowland soils and north-facing slopes. Fire history determines vegetation patterns, with successional stands of aspen and paper birch common throughout the region. White spruce eventually replaces aspen on south-facing slopes while white or black spruce replaces birch.

Vegetation patterns on the alluvial flood plain soils of the Tanana and Chena rivers are influenced by a succession pattern of vegetative species (Viereck 1970, Van Cleve et al. 1980). Willow and alder are the first to colonize new alluvial deposits, followed by balsam poplar. After the river terraces have been built to sufficient height by overbank sedimentation to prevent annual river inundation, white spruce seedlings establish themselves and eventually overtop the poplar. After approximately 200 years they eventually develop into thick pure stands of large white spruce. Over time, these white spruce stands can develop a thick moss layer; this layer insulates and cools the ground. As a result the ground may eventually become permanently frozen with a shallow wet root zone. The white spruce then gives way to black spruce, larch, and a thick sphagnum moss cover. This cycle is usually interrupted by periodic river bank erosion or forest fire before it undergoes the full cycle. A mosaic of vegetative patterns along the river floodplain is thus created through the successive vegetative patterns and superimposed burn areas.

Study area location

A 14-km stretch of the Tanana River centered on Goose Island, a large island located in the river center just south of Fairbanks, was chosen for a detailed analysis. This area was selected because it is the location of a causeway constructed in 1975 that obstructed a major channel of the river. Since the causeway was constructed prior to any in-river construction associated with the Tanana River Flood Control Levee, this site has been relatively undisturbed except for the building of the causeway. Analysis of this particular stretch of the river was made to gain insight into the response of a large river system to a major intrusion into its channel affecting the flow regime.

The Tanana River is composed of two main channels in the immediate vicinity of Goose Island. One channel is located on either side of Goose Island and several smaller associated islands. Figure 2 is a photomosaic of the study area taken 4 June 1982. Goose Island, two causeways linking Goose Island with the north bank, the reach of the river studied, and the Tanana River Flood Control Levee extending along the right (or north bank) of the Tanana are visible. An arbitrary baseline along the river as originally defined by Childers (1970) provides positioning along the river above the confluence with the Chena River.

A causeway (825 m in length × 12 m in width) extends due south from the north bank of the Tanana to the upstream end of Goose Island. Constructed in late 1975, it allowed development of Goose Island as a gravel source for construction in the Fairbanks area. The causeway completely obstructed the north channel of the Tanana River and reduced the active river width to 300 m in a single channel; prior to construction, the combined width was 1150 m.

A second, western causeway was constructed in early 1978. It extends from the north bank of the Tanana River to the western end of Goose Island, and was built to allow additional access for gravel removal. This causeway was extended to a small unnamed island southwest of Goose Island in the spring of 1979 to develop a large gravel pit on that small island.

Channel pattern

Near Fairbanks, the Tanana River undergoes a transition in channel pattern. Upstream of Fairbanks the braided river is characterized by unvegetated, unstable gravel bars and multiple channels. In contrast, downstream of Fairbanks the river changes to a more meandering pattern of one or more major channels with stable vegetated islands. Several side channels leave the river, and then rejoin it some distance downstream. The maximum length of these side channels, such as Salchaket Slough and Chena Slough, is 40 km; the side channels are characterized by a meandering planiform pattern and vegetated, stable banks. This latter pattern of several main channels with stable, vegetated islands and side channels has been defined by Mollard (1973) and Miall (1977) as an anastomosing pattern.

The change in channel pattern from braided to anastomosing correlates with a change of river slope in the Fairbanks area. The water surface slope of the Tanana at the USGS measuring site, "Tanana River at North Pole," averages 0.0012; the slope decreases to 0.0005 downstream of Goose Island and 0.0003 downstream of the confluence with the Chena River (Burrows and Harrold 1983).

Braiding and aggradation are not necessarily coincident (Fahnestock 1963). Braiding cannot occur without an appreciable bedload, but rivers that are in sediment transport equilibrium or even degrading can be braided.

Average meander wavelength of the main channel in the lower stretch of the study area, upstream and downstream of the Chena confluence, is approximately 2400 m with a width of the active floodplain varying between 600 to 2000 m.

River engineering history

Moose Creek Dike

Early river engineering projects had a significant impact on the hydrology of the Tanana and Chena rivers and must be understood to place the present study in perspective. Moose Creek Dike was the first major river engineering project in the Fairbanks area. It was authorized in 1938 and completed in May 1941 at a total cost of $557,000 (U.S. Army Corps of Engineers 1951). The dike was built to prevent floodwaters of the Tanana River from entering Chena Slough and causing flood damage to Fairbanks. Chena Slough (now often unofficially called Badger Slough) was one of several side channels of the Tanana River that left the main body of the river south of the present location of Eielson AFB and flowed northwest parallel to the main river for approximately 37 km. The Chena Slough joins the Chena River approximately 16 km east of Fairbanks. In fact, early settlers considered the mouth of the Chena River to be that junction and thought that the Chena Slough continued through town to its junction with the Tanana River 16 km downstream of Fairbanks (Ellsworth and Davenport 1915, U.S. Congress 1935). By the late 1930s, however, this lower stretch of the river was commonly referred to as the Chena River.

During high water periods a considerable portion of the flow in the lower Chena was contributed by Tanana River flow diverted through the Chena Slough. On 15 August 1933 city engineers estimated that the flow in the Chena River at Fairbanks was slightly over 200 m^3/s; approximately 140 m^3/s represented inflow from the Tanana River through Chena Slough (U.S. Congress 1938). City engineers claimed that inflow from the Tanana represented 70% of the Chena River flow at Fairbanks in 1933 (U.S. Congress 1938). During the 1937 summer flood an estimated 50% of the 620 m^3/s peak flow at Fairbanks was due to Tanana River overflow through Chena Slough (U.S. Congress 1938). Local residents were of the opinion that the slough was enlarging each year and, unless preventative actions were taken, a majority of the Tanana River flow might eventually be diverted into the slough, destroying the town site of Fairbanks (U.S. Congress 1938).

Moose Creek Dike consisted of an earthen dike (5 km long × 3 m high) which extended east–west from Moose Creek Bluff to the right bank of the Tanana River. It blocked the channel of Chena Slough 25 km southeast of Fairbanks. Following its construction, almost all the lower Chena flow was contributed from the Chena River. Chena Slough, upstream of its junction with the Chena River, has atrophied considerably over the years and is now much smaller and shallower than previously. The source of its present flow is groundwater input and local rainfall runoff. The present channel geometry and meander pattern of the lower Chena River is considerably different than that of the Chena River upstream of the junction with Chena Slough. This reflects the former combined higher flow regime of the Chena River and Chena Slough which formed the lower Chena. The ecology of the lower Chena has been changed considerably since the exclusion of the high suspended sediment-laden water of the Tanana River (Frey 1969, Frey et al. 1970).

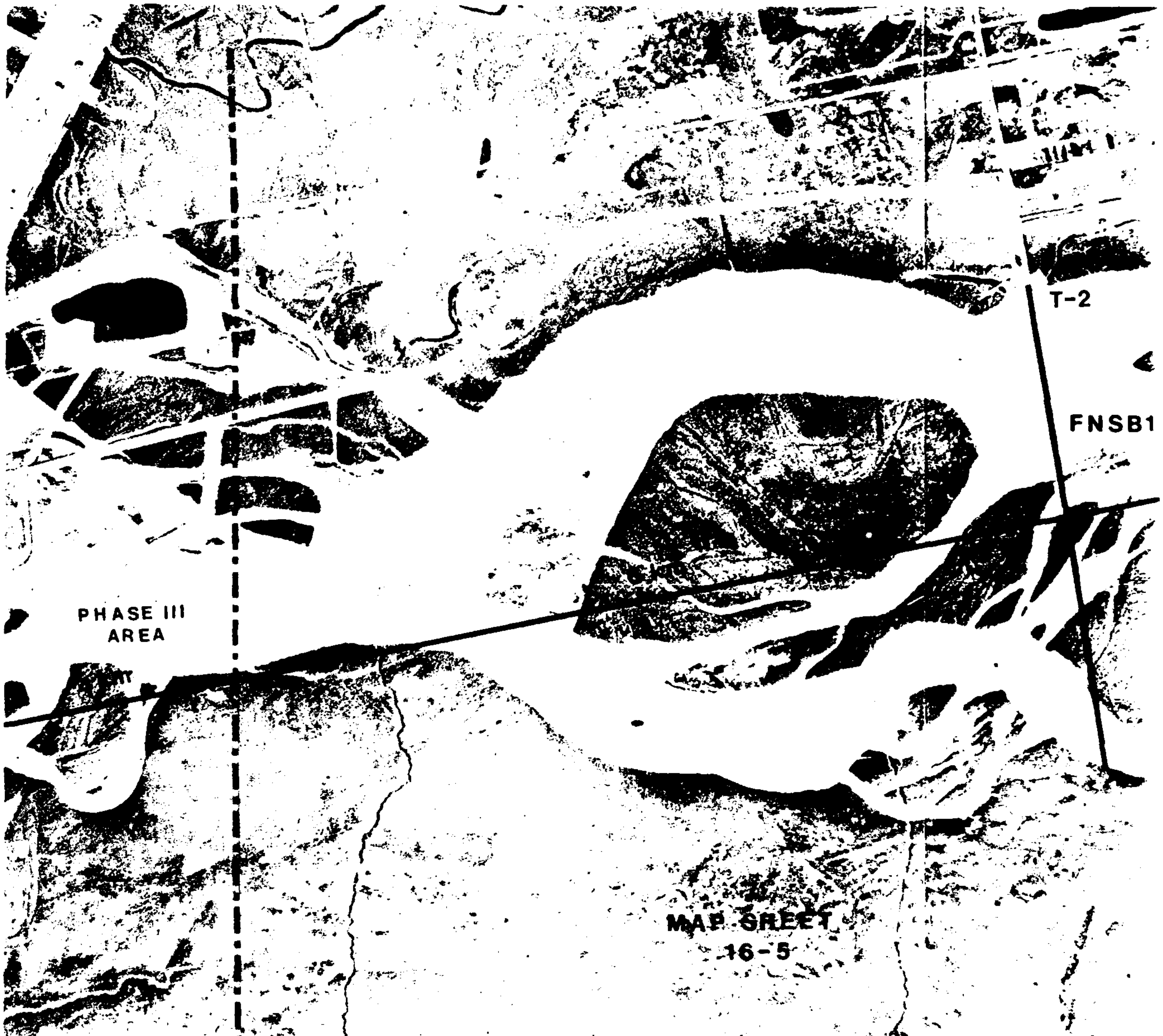
By 1960 the Tanana River had locally aggraded or built up bar surfaces 1.5 to 2 m on the south side of Moose Creek Dike (Péwé 1965). The diversion of Piledriver Slough (formerly the south half of Chena Slough) back into the Tanana had caused localized deposition of sediment on the south or upstream side of the dike. Extensive stands of willows and alders had established themselves on the aggraded bar areas by 1960.

1958 Chena Flood Control Plan

The 1948 spring flood of the Chena River was the highest flood of record prior to the August 1967 flood. Prompted by the 1948 spring flood, plans for further flood control protection on the Chena and Tanana rivers were authorized by the Flood Control Act of 1958. Plans were outlined in an interim report by the Corps of Engineers submitted to Congress in 1955 (U.S. Army Corps of Engineers 1951, U.S. Congress 1955). That report recommended construction of diversion and control works for flood protection at an estimated cost of $7,652,000 in 1955 dollars.

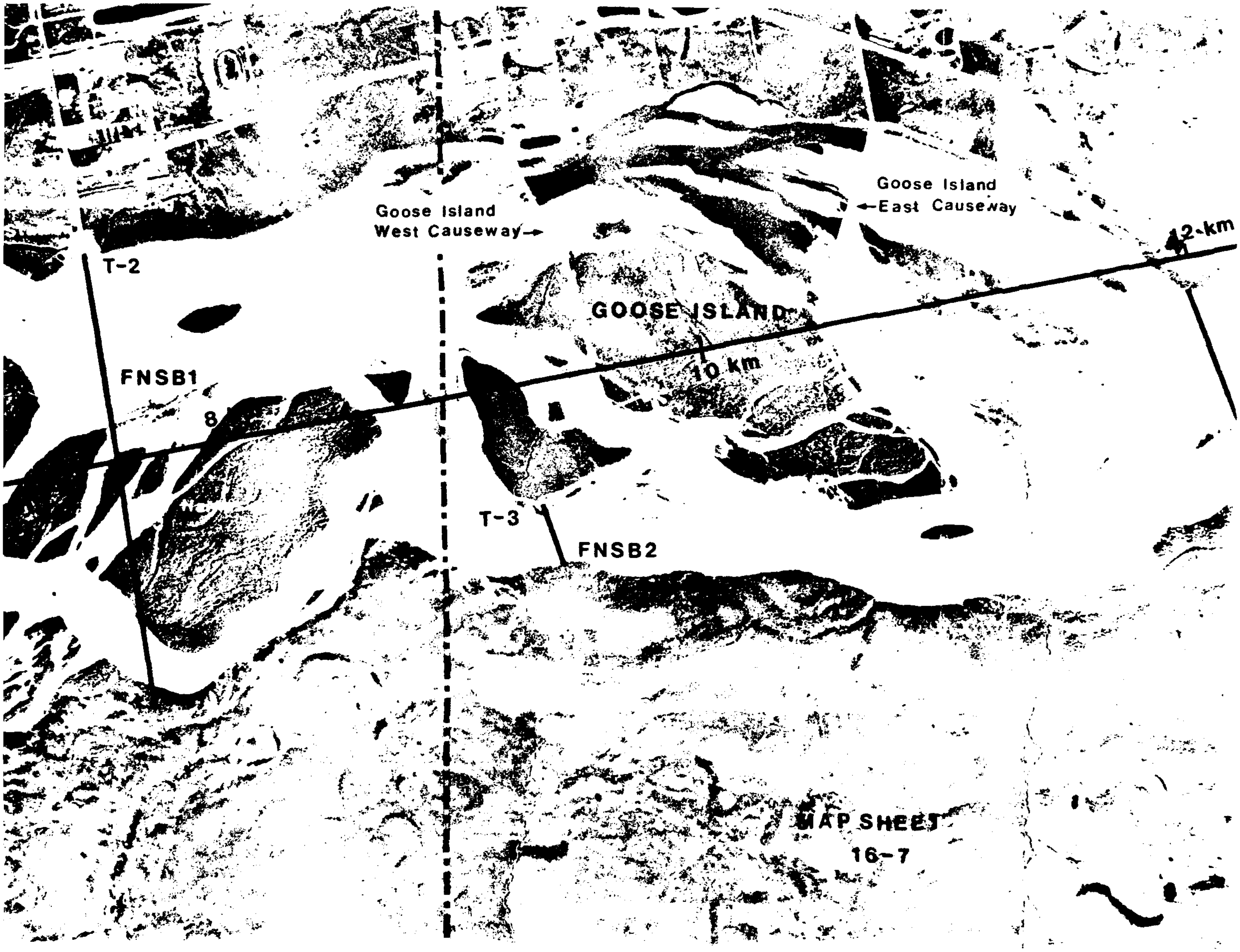
The plan consisted of three projects. First, a diversion dam was to be constructed on the Chena River above then Ladd AFB (which is now known as Ft. Wainwright) and downstream of the Chena Slough–Chena River junction. The proposed diversion dam would have been an earthfill structure with a maximum height of 11.3 m above the riverbed. It would have incorporated ungated control works that would permit a maximum discharge of 510 m^3/s. Second, a diversion channel would be constructed extending from the Chena River to the Tanana River. Third, approximately 19 km of levee was to be constructed extending from the diversion channel to the confluence of the two rivers.

The project plan was outdated by subsequent events. Those events included increased residential development in the general area, significant development on the project site, and new data from the Chena River Flood of

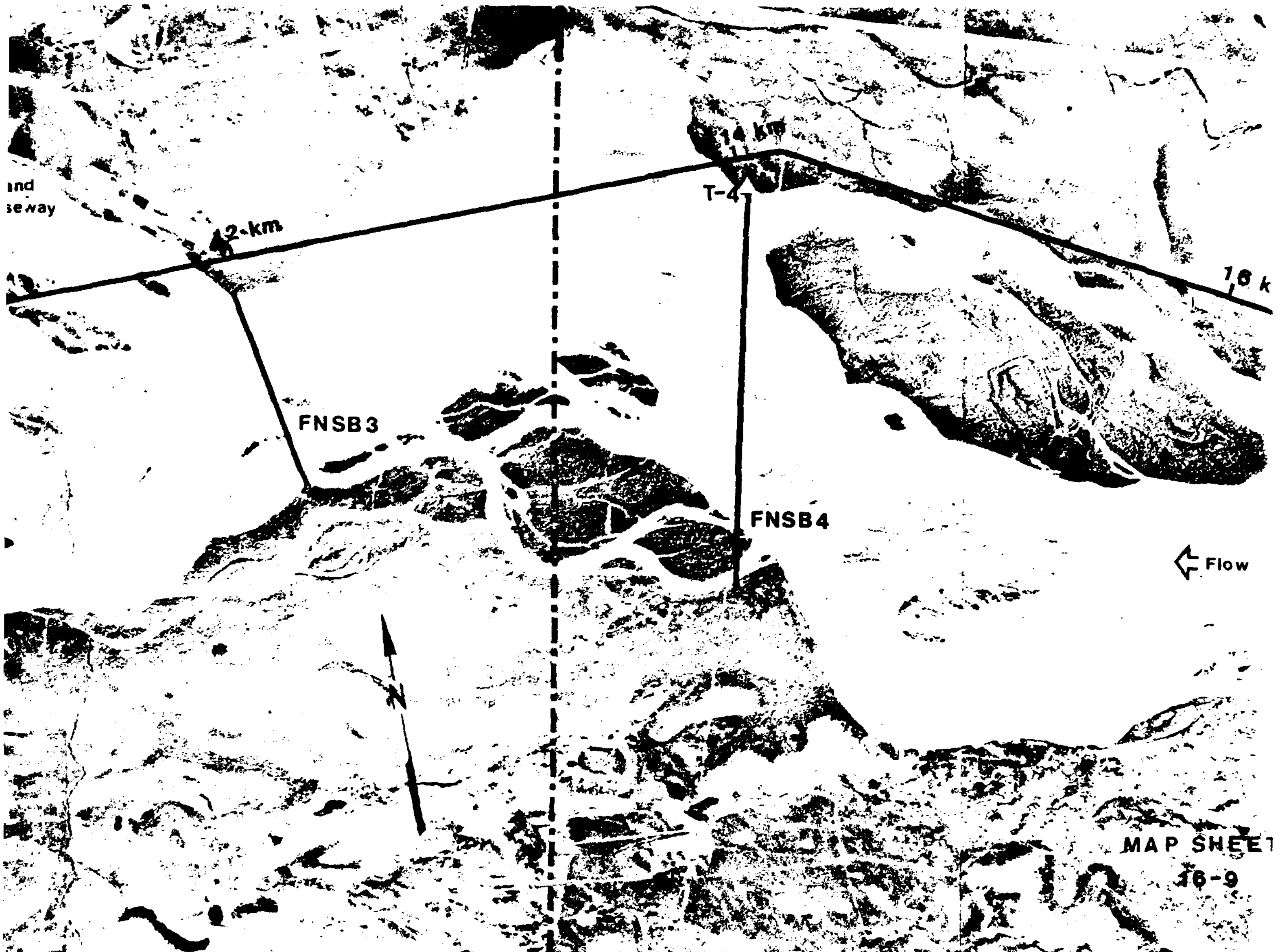


T-2
FNSB1
PHASE III
AREA
MAP SHEET
16-5

2


Goose Island
West Causeway
Goose Island
East Causeway
12 km
T-2
GOOSE ISLAND
10 km
FNSB1
8
T-3
FNSB2
MAP SHEET
16-7

3



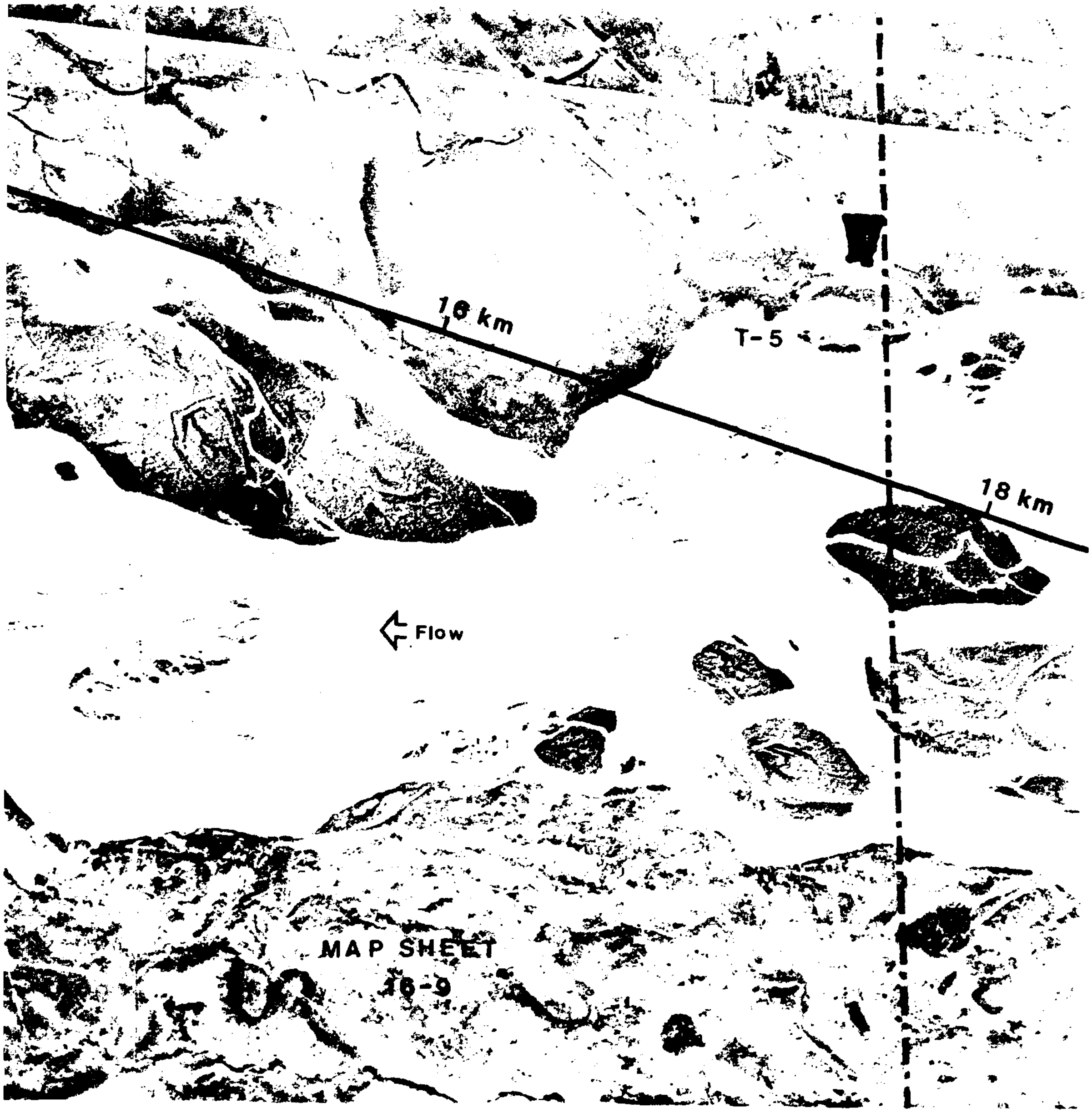


Figure 2. Photomosaic of the study area, 4 June 1982.

Record of August 1967, which was much larger than any previous flood.

1968 plan and present flood control project description

A much expanded project was authorized by the 1968 Flood Control Act (U.S. Army Corps of Engineers 1968). After several design changes, it evolved into the plan now nearing completion. Initial plans called for a dam and permanent reservoir on the Chena River located further upstream than the present dam location, hence the earlier name of "The Chena River Lakes Flood Control Project." Due to concerns about permafrost and permeability problems with the thick gravels underlying the area, the concept of a permanent reservoir was eliminated and the dam site was moved downstream to its present location. Also deleted was a planned dam on the Little Chena River, located northeast of Fairbanks.

The present project consists of two major components (Fig. 1). The first is the Moose Creek Dam which is a 12,400-m-long earthfill embankment that extends northeast to southwest from the bluffs north of the Chena River to the north bank of the Tanana River with a cleared drainage way behind the dam. The dam does not have a permanent reservoir and only holds water behind the dam when the flood gates are closed during high water events on the Chena River. The water is released back into the Chena as floodwaters recede. If sufficient water is impounded behind the dam, water can be diverted over a spillway at the southwest end of the drainage way into the Tanana River.

The second component of the flood control project is the Tanana River Levee System. This consists of a semipervious gravel levee that extends from the Chena Dam embankment westward approximately 32 km along the right (or north) bank of the Tanana River to just upstream of the confluence of the Chena and Tanana rivers. The levee system protects the city of Fairbanks from the floodwaters of the Tanana.

A series of groins or protective dikes have been built in stages to protect the levee from erosion from the Tanana. The levee alignment was originally designed so that there was a minimum 150-m buffer zone between the levee and the right bank of the Tanana. This vegetated buffer zone is designed to slow any overbank floodwaters, thus reducing any potential erosion. This buffer zone is also designed to slow ground-water seepage under the levee, thus reducing the potential for failure of the levee foundation due to piping. In one location, a protective groin was constructed when the river actually eroded within this 150-m buffer zone.

In other locations, a series of groins (a groin field) has been constructed to protect the levee from potential future erosion or to protect the levee from actual river flow. The so-called Phase III levee construction in the Airport area, 6 km downstream of Goose Island, consists of four protective groins, a pilot channel, and a levee alignment that cut off a former meander bend of the river. The construction of the levee and associated protective groins in several stages was an economic decision to extend construction costs over a number of years.

Gravel extraction operations

Several gravel extraction operations have occurred along the Tanana over the years, usually with little apparent effect on the river. One large gravel mining operation extracted gravel from 1969 to 1976 on the large point bar on the right bank of the Tanana, just upstream of the confluence of the Chena and Tanana rivers. Following the construction of the Goose Island Causeway, gravel has been extracted from the main channel on the south side of Goose Island from 1975 to the present. A small island to the southwest of Goose Island was a major source of gravel for construction of a portion of the Tanana River Levee during 1979 through 1981.

In 1969 an unauthorized gravel extraction operation took place along the right bank of the Tanana just upstream of the Fairbanks International Airport. A road was built across several side channels of the river north of the main channel to gain access to the widespread gravel bars in the area. The road blocked flow in the side channels. Starting in the early 1970s there was a significant increase in erosion at a meander bend of the main channel (located just downstream of the confluence of these side channels). This area of erosion is known as the "Airport Erosion Site" (Neill et al. 1984, U.S. Army Corps of Engineers 1968). Neill believed that the unauthorized blocking of the side channels was probably an important contributing factor to the substantial erosion in that meander bend. The erosion eventually threatened the railroad spur to the airport and was finally solved with the construction of the Phase III portion of the Tanana Levee. This river realignment cut off the meander bend and provided a new pilot channel to the south of the old bend.

Hydrology

A basic understanding of the hydrologic parameters of a river is required before one can understand the geomorphic processes within the river system. Detailed discussions of various aspects of the Tanana River hydrology are contained in Corps of Engineer Design Memoranda (U.S. Army Corps of Engineers 1971, 1972a, 1972b) and in Anderson (1970). Sediment transport in the Tanana has been addressed in a series of reports by the U.S. Geological Survey (USGS) (Burrows et al. 1979, 1981, Burrows and Harrold 1983, Harrold and Burrows 1983).

The total drainage area of the Tanana River basin is

115,500 km^2. The drainage area of the Tanana above the mouth of the Chena River is 53,468 km^2 (U.S. Army Corps of Engineers 1971). Bankfull flow of the Tanana River at Fairbanks is approximately 2270 m^3/s (U.S. Army Corps of Engineers 1971).

Burrows et al. (1981) derived relationships between discharge Q and water surface slope S for the two measurement sites on the Tanana River. The slope relationship for the Fairbanks site (located just downstream of the Fairbanks gauging site) is

$$S = 2.21 \times 10^{-4} Q^{0.115} \; (r^2 = 0.594).$$

The relationship for the sampling location near North Pole (located near the sill groin near Moose Creek Bluff) is

$$S = 2.29 \times 10^{-3} Q^{0.101} \; (r^2 = 0.758).$$

Additional slope data used in the Tanana Levee design are contained in the Design Memorandums (U.S. Army Corps of Engineers 1971, 1972a, 1972b, 1974, 1978).

Flood frequency

Original design work for the construction of the Fairbanks Flood Control Project was conducted during the late 1960s. Since no gauging station existed on the Tanana River in the vicinity of Fairbanks at that time, no Tanana River discharge data were available in the vicinity of the Flood Control Project. The design of the Tanana River Levee portion of the Fairbanks Flood Control Project was based on the Standard Project Flood (SPF) computed from estimated discharge levels under various scenarios. The SPF is the flood that should result from a storm of record that causes the most severe rainfall depth–area–duration relationships (Viessman et al. 1973). Estimated discharges for the Tanana River in the vicinity of the Flood Control Project as well as the SPFs for the Tanana River were calculated using the Streamflow Synthesis and Reservoir Regulation (SSARR) computer program (U.S. Army Corps of Engineers 1971).

Flow estimates used in the computer program were based both on discharge data from the USGS gauge downstream on the Tanana River at Nenana and on gauges upstream on the Tanana and various tributaries. Adjustments were made for the size of the drainage area of the Tanana Basin above Moose Creek Bluff to arrive with estimated discharges for the Tanana under various conditions (U.S. Army Corps of Engineers 1972b).

Two SPFs, one for summer and one for spring, were calculated. The summer SPF calculations were based on the storm of record and were calculated to be 3425 m^3/s (U.S. Army Corps of Engineers 1972b). The summer SPF is comparable to the estimated maximum discharge of 3500 m^3/s of the 16 August 1967 flood. This is to be expected since the same storm of record that produced the 1967 flood was used to calculate the SPF.

Table 1. Tanana River flood frequencies (U.S. Army Corps of Engineers 1972b).

Estimated by the U.S. Army Corps of Engineers during the design stage of the Fairbanks Flood Control Project.

Recurrence interval (years)	*Non-regulated floods Tanana River at Moose Creek Bluff (cfs)*	*(m^3/s)*
5	92,000	2,600
10	106,000	3,000
25	129,000	3,650
50	157,000	4,450
100	194,000	5,500

The spring SPF includes calculation of the maximum snow melt event at lower elevations in addition to the precipitation storm of record. The spring Standard Project Flood for the Tanana River at Fairbanks was calculated to be 7500 m^3/s. Since the spring SPF includes maximum snowmelt in addition to the maximum precipitation event, it was calculated to be over twice as large as the summer SPF.

Estimated flows generated by the SSARR program during the design of the flood control project were also used to estimate flood frequencies. Those flood frequencies are provided in Table 1. Estimated peak floods are higher than any of the annual peak flows subsequently recorded at the USGS Fairbanks gauge station "Tanana River at Fairbanks" (TRF) during the past 15 years.

In 1973 the U.S. Geological Survey installed a gauging station on the right bank of the Tanana at the end of Peger Road, co-located with the staff gauge site T2 (Fig. 1); 15 years of Tanana discharge data have been collected since then. Table 2 reports maximum flood events for the gauge "Tanana River at Fairbanks" for the 15 years of record.

As part of this report a flood frequency analysis was performed using the yearly maximum flood discharges collected since 1973. Analysis results were compared to the Flood Control Project design assumptions. An MS-DOS version of the flood frequency analysis program was used in this analysis (Paragon Engineering Limited 1983). The program analyzes the data using four different methods: Gumbel, log–normal, three-parameter log–normal, and log Pearson Type III methods. Although the results from each of the various methods were simi-

Table 2. Discharge data for flood frequency analysis (U.S. Geological Survey [1974–1986] and R. Burrows [USGS, personal communication 1987]).

Data were obtained from USGS Gauge Number 15485500, "Tanana River at Fairbanks."

	Annual peak flows (m^3/s)	*Annual peak flows* (*cfs*)		*Annual peak flows* (m^3/s)	*Annual peak flows* (*cfs*)
1973	1,780	(62,800)	1981	1,870	(66,100)
1974	1,680	(59,400)	1982	2,000	(70,400)
1975	1,940	(68,300)	1983	2,070	(73,100)
1976	1,500	(53,000)	1984	2,490	(87,700)
1977	1,780	(62,900)	1985	2,210	(78,000)
1978	1,710	(60,200)	1986	2,730	(96,400)
1979	2,130	(75,100)	1987	2,490	(88,000)*
1980	1,710	(60,500)			

*Provisional data.

Table 3. Tanana River flood frequency analysis.

Return period (years)	*Return probability (%)*	*Flood estimate* (m^3/s)	*Flood estimate* (*cfs*)
1.005	99.5	1,440	50,900
1.050	95	1,560	55,200
1.250	80	1,720	60,600
2.0	50	1,940	68,400
5.0	20	2,260	79,600
10.0	10	2,470	87,200
20.0	5	2,680	94,600
50.0	2	2,980	105,000
100.0	1	3,170	112,000
200.0	0.5	3,400	120,000
500.0	0.2	3,710	131,000

lar for the Tanana data, the log Pearson Type III maximum likelihood method was selected for the analysis in this study since this method is the accepted method for use by federal agencies (Benson 1968). The flood frequency computer program uses the Adamowski plotting formula (Adamowski 1981) in the calculation of the probability and return periods:

$$F_m = (m - 0.24)/(N + 0.5) \qquad (1)$$

where N is the number of years of record, in this case 15, and m is the rank of the recorded flood events. Table 3 provides the results of the flood frequency analysis using the log Pearson Type III method. Appendix A presents the complete results of the flood frequency analyses.

As indicated by flood marks at the gauge site, the flood of 16 August 1967 reached a stage of 132.28 m above mean sea level. The peak discharge was estimated to be approximately 3540 m^3/s based on extension of the stage/discharge relationships using standard methods (U.S. Geological Survey 1974). Determining stage/discharge relationships above flood stage on the Tanana, however, can be difficult because of the extensive floodplain of the Tanana extending south to Salchaket Slough and beyond. Figure 3 provides an example of the extension of stage/discharge relationships for the USGS gauge site T2 on the Tanana River at Fairbanks.

The stage and discharge of each of the annual peak flows since 1973 are plotted in Figure 3. In addition, the stage and estimated discharge of the 1967 flood is plotted. And finally, the stage and discharge of the spring SPF is also plotted. During the the design of the Tanana River Levee, the Corps of Engineers used a series of

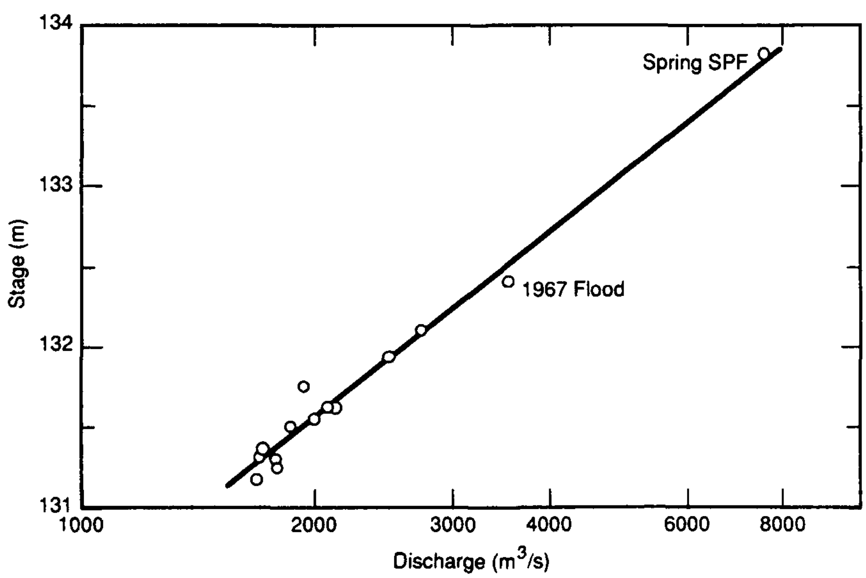


Figure 3. Plot of stage and discharge relationships for USGS gauge site T2.

cross sections of the Tanana River floodplain and the computer program HEC-2 to calculate the spring SPF water surface profile using the step backwater method (U.S. Army Corps of Engineers 1978).

The estimated peak discharge for the 16 August 1967 flood (hollow triangle) was plotted on the graph of the results of the flood analysis done using the fifteen years of discharge data (Fig. A1). Where the maximum likelihood line intersects a discharge of 125,00 cfs, the graph shows a return probability of 0.3% or a return period of 333 years. Generally, when data records are as short as those available for the Tanana, extensions of flood frequency estimates are not recommended beyond 50 years (Childers 1970). The error percentages in this range are quite high, about 20%, making the return probability almost meaningless. Alternatively, the return period for the 1967 flood in the original estimated flood frequency analysis by the Corps of Engineers of approximately 25 years is obviously too low when compared to the subsequent record.

During the 1967 flood Chena River floodwaters, when added to the Tanana River floodwaters below the site of the USGS TRF gauge, significantly increased the flood stage of the Tanana downstream of the confluence of the two rivers. The increase in flood stage is visible in the plots of water surface profiles of the 1967 flood (Fig. A4, U.S. Army Corps of Engineers 1972a). The flood profile rises significantly in the vicinity of the confluence of the two rivers. The 1967 Tanana flood below the confluence of the Chena River was a significantly larger flood event than the 1967 flood at the USGS TRF gauge site upstream of the confluence.

Although the methods used to determine flood frequency during the design stage of the flood control project differ from the flood frequency analysis done for this report, comparison of the results of the two different analyses is interesting. The design criteria used by the Corps of Engineers exceeds any expected flood event predicted from the flood frequency analysis done here.

Floods are very important from a geomorphic point of view. They greatly affect a river system, causing significant changes in a short period of time. The timing and magnitude of past flood events should be understood as much as possible when reviewing the geomorphic history of any river system.

Materials and sediments

Bed materials and sediment transport. Particle-size distributions for bed material samples at the two USGS gauging sites is given in Burrows et al. (1981). At the USGS Fairbanks site, the median particle size of bed material in the overflow parts of the channel is in the medium sand range and is in the gravel range in the main channel. At North Pole, the median particle size is in the gravel range. Largest particles at North Pole ranged between 64 and 128 mm; at Fairbanks particles ranged between 32 and 64 mm.

Average annual sediment load is 24 million metric tons of suspended sediment and 321,000 metric tons of bedload at the Fairbanks site (Burrows et al. 1981). Bedload averages 1.34% of the suspended sediment load (Burrows et al. 1981). Neill (1984), in studying erosion at one bend of the Tanana River in a single channel stretch of the river, concluded that the average annual volume of bed-material eroded from the bend was approximately the same as the average annual bedload transport in the river measured at a site just upstream. The bedload in the river was undergoing complete replacement. The bedload moving downstream was deposited in a point bar opposite the bend undergoing rapid erosion and was replaced in the river system by bank material being eroded from the bend.

Bank materials and floodplain development. The floodplain deposits of the Tanana River in the vicinity of Goose Island and downstream are similar to those described by Wolman and Leopold (1957) and Miall (1977). The deposits consist of coarse-grained lateral-accretion deposits over-topped with a veneer of overbank (vertical-accretion) sediments. Bank material consists of up to 3 m of interbedded silt and sands formed by overbank flood deposits overlying river bar gravels.

Viereck (1970) and Van Cleve et al. (1980) demonstrate that the establishment and forest succession relationships on the Tanana River floodplain are directly related to the buildup of finer-grain overbank sedimentation on the bare gravel bar lag deposits of the Tanana. Two-hundred-year-old mature white spruce forests occur on river terraces that are approximately 2 m above the gravel bars exposed at river low water levels.* Drill logs from the construction of the Tanana Levee show that average thicknesses of silt and sand sediments over gravel deposits range between 2 and 3 m.

An analysis of white spruce forest succession relationships on the inside bends of a meandering river system in northern British Columbia shows that rapid sedimentation on floodplain surfaces from overbank flow declines after 50 years (Nanson and Beach 1977), with white spruce seedlings establishing themselves after 60 years once the floodplain is sufficiently built up to protect the seedlings from frequent inundation. From approximately 50 to 250 years, sedimentation continues but at a much slower rate; beyond 250 years there appears to be a negligible change in floodplain elevation due to sediment accumulation.

* L.Viereck, Institute of Northern Forestry, USFS, personal communication 1987.

Bank erosion processes

Individual channels within the multiple-channeled Tanana River system act as meandering channels; maximum erosion occurs on the outside of bends and deposition occurs on the inside of meander bends. The erosion of the outside channel bends occurs either along high, vegetated banks of the floodplain or along large in-river islands. However, the heavy bedload of the Tanana, with numerous in-channel bars forming and reforming, increases the complexity of the river system beyond that of a simple meandering river.

Bank erosion processes within the Tanana River are similar to processes described for other rivers. These erosion processes include "corrosion" or direct shearing off of material of the bank at high flows (Hooke 1979). Subaerial overhangs often remain bound by the upper vegetation mat; overhangs are particularly present when flow has only approached bankfull. These overhangs are weakened, eventually drop off, and are swept away by later high flows.

Thorne and Tovey (1981) described "cantilever failure" noting that alluvial deposits often have a composite structure of less cohesive sand and gravel overlain by cohesive silt or clay. Bank erosion occurs by fluvial entrainment of material from the lower cohesionless bank at a much higher rate than the upper bank. Undermining occurs which leads to cantilevers of overhanging upper bank material which then fail and fall into the river. The blocks of soil are then removed by fluvial entrainment. Cantilever failure also occurs in frozen bank material when thermal niches form at the water level resulting in an overhang of still frozen material (Lawson 1983). Rotational sliding caused by erosion and undercutting of the toe of the bank producing multi-stepped bank profiles (Colman 1969) also occurs to some degree.

Another major type of bank erosion occurs when saturated bank material slumps or collapses outward. The material is then removed or eroded by fluvial action. Bank material can become supersaturated and flow outward under certain conditions. This often occurs after the flood peak has passed and ground water is flowing back into the stream. Several large semicircular slump areas have been observed by the author along the north bank of the Tanana River where slumping or flowing of the bank material has occurred. The overlying vegetation mat has collapsed uniformly downward 0.5 to 1 m with the total slump area covering several hundred square meters.

Channel migration rates at bends are measured as the maximum outer bank displacement through time at right angles to the former channel axis (Hickin 1974). In meandering river systems, channel migration rates are strongly controlled by bend curvature. Hickin and Nanson (1975) found that bend migration reaches a maximum value as the curvature ratio approaches 3 and declines rapidly on either side of this ratio value. Curvature ratios for individual channels of the Tanana as calculated for this report are much lower than 3, ranging from 1.3 to 1.5.

Nanson and Hickin (1986) determined the erosion rates of meander bends in eighteen river stretches in western British Columbia. Combined with sediment size at the base of the outer bank, differences in river size or scale explained almost 70% of the total increase in rates of bank erosion. Bank erosion and channel migration are hypothesized by these authors to be largely determined by bed-material transport. A simple relationship involving stream power and basal sediment size provides means of expressing the driving and resisting forces of predictive models. Total erosive energy available to large rivers contributes to higher erosion rates. Holding river scale constant, Nanson and Hickin (1986) found that the size of basal sediment in the outer bank is influential in determining erosion rates.

Bank failure due to erosion and channel migration is a discontinuous or episodic event. Short-term migration rates are not necessarily representative of long-term averages. Nanson and Hickin (1983) documented channel migration rates of 0 and 5 m per year over a 21-year period for two similar stream bends, yet found that the approximate channel migration rates determined from the forest succession in each bend was 1.8 and 1.4 m per year over a 120-year period.

These differences in erosion rates based on different time scales are important when interpreting the results of the present analysis. The period of record studied in this report is too brief to account for all normal variations in rates of bank recession and channel changes in a river system as large and complex as the Tanana River. Maximum erosion rates observed over the last 45 years are by no means the maximum natural rates that may possibly occur over a longer time span.

METHODS

Single channel meandering streams have been the site of most studies of fluvial erosion rates (i.e., Hagerty et al. 1981, Hicken 1974, Hicken and Nanson 1975, Nanson and Hicken 1986, Hooke 1979, 1980, Leopold and Wolman 1960). Other studies have examined shoreline erosion rates (Spoeri et al. 1985, Dolan et al. 1979, 1980, Gatto 1978, 1982).

Most studies on single channel meandering rivers have concerned themselves with bank recession rates and rates of meander migration rather than total erosion rates. Single channel meandering rivers lend themselves to a straightforward analysis using sequential air photography to measure changes in bank line position from year to year.

Determination of the total amount of erosion which occurs in any river, but especially in a large river the size of the Tanana, is difficult. The logistics required to establish and perform repeated surveys of a sufficient number of river channel cross sections on a river the size of the Tanana may not be appreciated until attempted. Several problems must be overcome. First, determination of location on the river is difficult at times due to the large size, multiple channels and lack of distinctive landmarks visible from water level. Second, although the Corps of Engineers established a series of cross sections that were periodically surveyed as part of the monitoring of the Tanana, long distances between cross sections and limited times for measurement of the cross sections fail to provide sufficient information to determine volumetric amounts of eroded material. Finally, no historical cross-sectional data exist prior to 1969 that would allow analysis of river activity prior to major in-river construction.

There are some cross sections available for the Tanana River with multiple years of data. However, most of these are located within the Phase III realignment area and in the vicinity of the confluence of the Chena River, both downstream of the study area (Chacho et al. 1982, 1984a, 1984b, Neill et al. 1984, Chacho and Vincent 1985). Many other cross sections only have one or two years of survey data, which make them almost worthless for determining periodic changes in channel area or bank position. Four cross sections within the study area did have multiple years of survey data; these data are compared with data from the aerial photography analysis.

Because the amount of volumetric erosion could not be quantified to any degree of confidence, aerial photography is used to determine areal extent of erosion over time. Use of aerial photos allows a historical perspective on river activity prior to major disturbance of the river caused by construction activity associated with flood control or gravel extraction.

Data sources

Several factors complicate the data available for analysis. These factors include the timing of erosion, river discharge levels and variable quality aerial photography coverage. Each is subsequently discussed.

The timing of erosion in the Tanana River is the first complicating factor. Because of long winters and resulting low flow and ice cover on the river during much of that time, river bank erosion is confined to approximately six months of the year. These periods of alternating active erosion and relative quiescence complicate determination of rates of erosion; this determination is especially difficult over time periods of varying lengths.

A second factor is the various river discharge levels present when aerial photography of the river was taken. These varying discharge levels can affect interpretation of river bank line positions and bar locations.

A series of historical aerial photographs of the Tanana River covering a 45-year record extending from 1938 to 1982 were used to map changes in the study area for nine separate time periods. Aerial photography of parts of the study area was available for a number of dates from 1938 to the present. The photography was originally obtained by various agencies including the Army Air Corps, U.S. Air Force, Soil Conservation Service, U.S. Geological Survey, and Corps of Engineers.

Ten sets of aerial photographs covering the entire study area were selected to provide the best coverage of the river. These sets define a series of time periods used in analysis of erosion rates and channel changes. The time periods bracketed by the aerial photography dates are defined in Table 4. The nine time periods range in duration from 12 years to less than one year. In order to more accurately compare erosion rates that have occurred in two different time periods, a time frame based on an "effective erosion year" was adopted. The concept of an "effective erosion year" for the Tanana River was developed by J. S. Buska (of CRREL) and this author for use in analysis of erosion at the airport erosion site, the location of the Phase III staged construction of the Tanana Levee and associated protective groins across the bend of the Tanana, downstream of the present study area (Neill et al. 1984).

This concept of an effective erosion year is based on the premise that all of the erosion occurs from 1 May through 31 October. During this time period approximately 95% of the river's annual discharge occurs (Neill et al. 1984, Lawson et al. 1986). While two different time periods may extend over widely different lengths of time, those differing time periods may have similar effective erosion times. For example, a time period between two sets of airphotos taken on 1 September 1980 and 1 June 1981 has a total of three effective

Table 4. Time periods used in the airphoto analysis.

Period	*Duration*	*Length (years)*
1938–48	10 July 1938 to 4 June 1948	9.57
1948–61	4 June 1948 to 1 May 1961	12.81
1961–70	1 May 1961 to 12 May 1970	9.07
1970–74	12 May 1970 to 19 Sept. 1974	4.77
1974–76	19 Sept. 1974 to 4 June 1976	1.42
1976–78	4 June 1976 to 4 June 1978	2.00
1978–79	4 June 1978 to 3 July 1979	1.16
1979–80	3 July 1979 to 7 May 1980	0.69
1980–82	7 May 1980 to 4 June 1982	2.15

erosion months (September, October and May) or one-half of an effective erosion year. This period is time equivalent to another period based on airphotos taken on 1 May 1982 and 1 August 1982 covering three effective erosion months or one-half of an effective erosion year. An exact time based on an effective six-month erosion year of May through October was derived for each of the time periods. This "effective erosion year" allows a more accurate determination of the rate of erosion during each time period.

The aerial photography available for this study was taken at various times of the year and at various river discharge levels. For example, some photographs were taken in years when river discharge was less then 600 m^3/s and numerous river bars are visible above the water surface. But some photographs from other years were taken when river discharge was near bankfull flow of 1500 m^3/s or more and all bars are flooded. However, in all the photographs used in the analysis, the right and left vegetated bank lines and the bank lines of vegetated islands that delineate the active river system are sharply defined and little changed by river stage level at the scale of the photos used for the analysis.

Prior to September 1973 the USGS Water Resources Division did not maintain discharge records of the Tanana River in the Fairbanks area (USGS 1974). The nearest discharge measurements were made at Nenana, located 80 km downstream. The Nenana gauge was established in 1962. Prior to that time, there was no gauge on the Tanana closer than Tanacross, and so no estimates were made on the discharge for the photography prior to 1962. For the 1970 photography, estimates of the discharge for the date of the photography were made based on the Nenana records. The annual average Tanana River at Nenana discharge records run approximately 24% higher than discharge of the Tanana River near Fairbanks. From water year 1974 to present, discharge records are available from the USGS gauge "Tanana River at Fairbanks." This gauge was originally located within the study area at the south end of Peger Road, collocated with the water surface elevation site T2 (Fig. 2). The gauge was moved in June 1985 to the end of a groin farther downstream near the Fairbanks International Airport (USGS 1986).

Table 5 lists the dates of the aerial photographs used for the study and the estimated or measured average daily river discharge on the date the aerial photographs were taken. The lack of measured discharge data prior to 1974 did not materially affect the analysis since the discharge data were not critical to determining riverbank positions as defined for this analysis. Even though the discharge data are not critical in the airphoto analysis they are presented here for informational purposes.

Table 5. Aerial photography dates and average river discharge.

Date of aerial photography	*Scale and type of photography*	*Estimated or measured average daily discharge on that date (cfs)*	*(m^3/s)*
10 July 1938	1:12,000 B&W	N.A.	
4 June 1948	1:10,000 B&W	N.A.	
1 May 1961	1:12,000 B&W	N.A.	
20 May 1970	1:12,000 B&W	14,500*	410
19 Sept 1974	1:12,000 B&W	19,100	540
4 June 1976	1:12,000 B&W	31,200	880
4 June 1978	1:12,000 B&W	21,600	610
3 July 1979	1:12,000 color & 1:24,000 B&W	47,500	1,350
7 May 1980	1:12,000 color & 1:24,000 B&W	17,700	500
4 June 1982	1:12,000 color & 1:24,000 B&W	48,400	1,370

*Estimated from Tanana River at Nenana data.

Procedure

A base year was selected to provide a standard for comparison. Photographs from all other years were compared to this base year. Use of a base year allowed photographs from all years to be standardized to one scale, thus allowing accurate comparisons between bank line positions from different years. A set of airphotos of the Tanana River from 7 May 1980, at an original scale ratio of 1:24,000, was selected as the base year. Airphotos from all other years, both before and after 1980, were compared to this base year. Three photos from flight line 16 of the May 1980 photography were selected that provided complete coverage of the stretch of the river to be analyzed. The original photography of flight line 16 provided complete stereoscopic coverage with 60% overlap between adjacent photos. The three photos selected were alternate photos from flight line 16 and provide a 20% overlap with the next photo. The photos were enlarged to a scale ratio of 1:4700 from the original scale, producing a set of three 105-cm x 105-cm photo base maps.

The identification number assigned to each of these three photo base maps is the same as the number on the original airphotos. Photo 16-5 covers the river study reach downstream of Goose Island, photo 16-7 covers the reach on either side of Goose Island and photo 16-9 covers the reach upstream of Goose Island. Each photo covers 5.42 km on the ground. With the 20% overlap between each photo, a maximum of 14.10 km is covered by the set of three photos. A detailed photo-analysis of the riverbank positions and bank erosion rates was conducted using these three photo base maps.

A Bausch and Lomb Zoom Transfer Scope was used to project the image of airphotos from each year onto a separate transparent Mylar overlay registered to the 1980 photo base map underneath. The use of the zoom transfer scope allowed the superimposition of the two photo images, correcting for differences in scale, as well as distortions in the photographs. The two photo images were aligned by superimposing common points in the images such as small ponds, meander scars, buildings or other distinct natural or man-made features. Once the two photo images were superimposed, differences in riverbank positions were visible and plotted onto the overlay.

Approximately a dozen setups with two to three overlapping airphotos were required to produce one 105-cm × 105-cm overlay of the same area of the base photo. The product of this process was an overlay of the river bank line positions for a single year plotted to the scale of the underlying 1980 photo base map. The process was repeated for each of the other two 1980 photo base maps, resulting in three overlays for each of the nine years analyzed, a total of 27 separate 105-cm × 105-cm overlays.

Once overlays for each year were completed, the bank line positions for each overlay were combined and plotted together on a summary overlay. This process was simplified by the registration of the overlays that allow each to be superimposed exactly. After overlap and elimination of 10% on the outer ends of the two end photos (to reduce edge distortions in the original photos), each of the summary overlays covered a 4.34-km stretch of the river. The three overlays together totaled 13.01 km of river. On the summary overlay, bank positions were redrawn whenever the bank line had changed from the prior overlay. As each overlay was added, a succession of bank line positions was assembled showing the history of bank line recession over time. The area between two successive bank line positions was the area eroded during the time period defined by the dates of the two different bank lines.

In order to allow consistent photointerpretation between different years, criteria for determining mappable bank line positions had to be defined. Bank lines were defined for the purpose of this study as the edge of any vegetated area, either part of a vegetated island or part of the left or right main bank. This definition reflects the assumption that the presence of vegetation marked a more permanent and higher surface than the more ephemeral bare gravel bars. Determination of sufficient vegetation to categorize a gravel bar as a stable, vegetated area is an arbitrary decision made during the photointerpretation process. Careful attention is required when mapping bank lines with large trees. Tree shadows tend to obscure the actual bank line; bank line positions can be erroneously mapped several meters into the river.

Depositional areas are not as well defined or as easy to measure as erosional areas. Their date of formation is especially difficult to pinpoint exactly. Gravel bars are stabilized in the river as they build up over several years by normal, periodic overbank sedimentation during high water periods. When the bar surface is high enough above normal water levels, vegetation establishes itself and further stabilizes the bar. At some point an arbitrary decision is required of the photointerpreter that the area is now a permanent land surface and no longer an ephemeral bar. The bank lines of these newly stabilized areas were either mapped as vegetated islands or as additions to the right and left main banks. These areas were then measured and added to the depositional area totals for that time period. So, although an area may be built up over several time periods, it is assigned to only one time period. This may tend to bias the rate of deposition and mask the exact time period when deposition starts or concludes in a particular reach of the river.

In subsequent time periods parts of these depositional areas were in turn eroded. Once eroded, the measured areas were included in the eroded area totals. It is possible that one area may undergo several cycles of bar establishment, buildup and stabilization by vegetation, to be followed by subsequent erosion.

The areas between bank lines were measured by electronic digitization. The total areas of erosion and deposition were calculated for each time period. A Hewlett-Packard (HP) 9836 computer and a HP 9874A electronic digitizing board were used to digitize each of the erosional areas on the map sheets and to calculate the actual areas of erosion in square meters. The digitization process involves moving a cursor around the perimeter of the area being measured. The computer determines the X and Y positions of the cursor as it moves around the perimeter and then calculates the area enclosed by the traced line. This process is similar to that used with a planimeter. A computer program then converts the actual calculated area to an equivalent area based on the map scale and displays the area as square meters. To account for small errors in the digitizing process, mainly introduced while tracing the line by hand with the cursor, each area was digitized at least three times and the three calculated areas were averaged for the final area value. The three values were always within 3% of each other. Once the average values for all of the erosional areas for one time period were measured, they were then added to obtain the total erosion in square meters for that time period. The same procedure was repeated for areas of deposition.

Figures B1, B2 and B3 are the summary overlay maps showing the areas of erosion and deposition for map sheets 16-5, 16-7, and 16-9.

Measurement errors

Errors inherent in measuring positions of shorelines from airphotos are discussed in detail by Stafford (1972) and Dolan et al. (1980). Dolan et al. used scales of maps and photographs (1:5000) comparable to those used in this study. The errors in measurement of shoreline or bank line positions are composites of the errors of each of the processes used in the analysis. Measurement errors are introduced during measurement due to difficulty in estimating the edges of an object on the enlarged photograph when transferring the image on the Zoom Transferscope. Dolan et al. (1980) estimated mechanical measurement errors of a line position to be as large as 2.5 m of ground distance.

Since Dolan et al. (1980) measured shoreline recession rates, they were interested in the errors associated with measuring distances between two successive shoreline positions. Since this study measures areas of erosion, the error in determining a line position is increased when multiplied together to obtain an area. For a small area the error can be quite significant. For example, a 10- × 100-m area of erosion delineated by two successive bank line positions is typical of some of the smaller areas measured. The area is actually 10 m ±2.5 m × 100 m ±2.5 m. The total of this area then ranges from a possible 730 m^2 to 1280 m^2 which is equivalent to 1000 m^2 ±275 m^2 or 1000 m^2 ±27.5%. A larger 100- × 100-m area ranges from a possible 9500 m^2 to 10,500 m^2, which is equivalent to 10,000 m^2 ±500 m^2 or 10,000 m^2 ±5%. For even larger areas, the percentage error is correspondingly smaller:

$$200 \pm 2.5 \text{ m} \times 200 \pm 2.5 \text{ m} = 40{,}000 \text{ m}^2 \pm 2.5\%$$

$$500 \pm 2.5 \text{ m} \times 500 \pm 2.5 \text{ m} = 250{,}000 \text{ m}^2 \pm 1\%$$

Based on the average size of the measured areas of erosion and deposition, the percentage error due to measurement error is approximately ±5%.

The second component of error is associated with the digitizing process, where, with repeated measurements, the digitized areas were within 3% or ±1.5%. Total error, then, for a measured area of erosion would be on the order of ±6.5%.

RESULTS

This section presents the results of the airphoto analysis of erosion and deposition. Rates of erosion and deposition are derived for each time period. Data on changes in water surface slopes and selected river cross sections within the study area are discussed and compared with the results of the airphoto analysis. Additionally, the results of a topological analysis to determine the change in amount of braiding in the river over time are presented.

Erosion and deposition analysis

Appendix A provides all the data on erosion and deposition areas measured on the three map sheets for each of the time periods. Tables 6 and 7 are summary tables that list the total erosion and deposition areas for each time period and map sheet.

The totals of erosion and deposition are subdivided into three types by location within the river channel (either right bank, left bank, or in-river island locations). After total erosion had been determined for each type of location, rates of erosion were computed for each time period. Total erosion in square meters was divided by the length of each time period to determine the rate of land erosion or deposition per year. This erosion rate was calculated for each map sheet as well as for the total study reach.

In order to compare more localized erosion rates for different areas of the river, the erosion rate for each map sheet was then divided by the length of each of the map sheets (4.34 km) to determine the area eroded per kilometer length of the river per year. The total erosion rate for the time period was divided by the length of the river covered in the total study reach, 13.01 km, to obtain the average erosion per kilometer length per year for the entire study reach. The six-month effective erosion year is used in the computation of erosion rates to equalize the times when erosion or deposition actually occurred.

Table 8 summarizes the erosion rates for each time period. The process was repeated when calculating deposition rates. Table 9 summarizes the deposition rates for the time periods.

Using the erosion rate data presented in Table 8, other erosion rates can be easily derived for comparative purposes. For example, during 1976–78 erosion on the right bank of the river for the entire study reach totaled 62,600 m^2. The erosion rate for the right bank during this period was 31,300 m^2/yr or 2,510 m^2/km. This erosion rate per kilometer of riverbank can be converted directly into an average bank recession rate of 2.51 m/yr per meter of riverbank length.

While each time period is discussed subsequently in detail, the data from Tables 8 and 9 are presented graphically in a series of figures. The erosion rates shown in Figure 4 indicate that, generally, average erosion over the entire study period has not varied dramatically. The sole exception occurs for a brief time in period 1979–80 when the rates were elevated above the long-term rates.

Figure 5 presents average erosion rates for each map sheet. Erosion during time periods 1979–80 and 1980–82 was greater downstream of Goose Island (map sheet 16-5), and was lower upstream of Goose Island (map sheet 16-9).

Figure 6 presents the average deposition rates for the entire study area. The rates display greater variability than the erosion rates with deposition peaks in period

Table 6. Erosion area summary (area in square meters).

Period		*Map sheet* 16-5	16-7	16-9	*Total*
1938–48	Right bank	89,300	119,200	50,300	258,800
	Left bank	57,500	49,900	1,500	108,900
	Islands	142,700	49,500	76,600	268,800
	Total	289,500	218,600	128,400	636,500
1948–61	Right bank	149,500	116,600	157,100	423,200
	Left bank	111,100	31,900	155,500	298,500
	Islands	123,800	87,900	178,700	390,400
	Total	384,400	236,400	491,300	1,112,100
1961–70	Right bank	83,900	97,700	192,300	373,900
	Left bank	33,100	81,200	74,000	188,300
	Island	68,900	81,200	95,700	245,800
	Total	185,900	260,100	362,000	808,000
1970–74	Right bank	44,400	50,800	38,800	134,000
	Left bank	33,700	2,880	14,400	76,900
	Islands	46,000	54,000	16,900	116,900
	Total	124,100	133,600	70,100	327,800
1974–76	Right bank	10,900	0	21,700	32,600
	Left bank	17,700	7,400	0	25,100
	Islands	0	35,600	5,000	40,600
	Total	28,600	43,000	26,700	98,300
1976–78	Right bank	22,700	20,700	16,600	60,000
	Left bank	5,700	0	0	5,700
	Islands	15,400	35,300	8,800	59,500
	Total	43,800	56,000	25,400	125,200
1978–79	Right bank	0	20,200	4,800	25,000
	Left bank	0	0	0	0
	Islands	10,400	18,000	3,600	32,000
	Total	10,400	38,200	8,400	57,000
1979–80	Right bank	0	8,500	9,100	17,600
	Left bank	13,900	0	0	13,900
	Islands	39,700	24,800	3,200	67,700
	Total	53,600	33,300	12,300	99,200
1980–82	Right bank	0	0	7,800	7,800
	Left bank	56,000	43,200	0	99,200
	Islands	54,300	19,300	7,600	81,200
	Total	110,300	62,500	15,400	188,200

Table 7. Deposition area summary (area in square meters).

Period		*Map sheet* 16-5	16-7	16-9	*Total*
1938–48	Right bank	11,900	0	0	11,900
	Left bank	3,900	0	0	3,900
	Islands	26,400	19,500	33,300	79,200
	Total	42,200	19,500	33,300	95,000
1948–61	Right bank	0	0	6,000	6,000
	Left bank	214,000	0	2,900	216,900
	Islands	93,000	42,900	45,000	180,900
	Total	307,000	42,900	53,900	403,800
1961–70	Right bank	7,000	0	0	7,000
	Left bank	41,400	185,600	109,100	159,000
	Islands	502,000	70,300	34,900	607,200
	Total	550,400	255,900	144,000	950,300
1970–74	Right bank	8,000	0	0	8,000
	Left bank	6,000	0	0	6,000
	Islands	41,300	20,400	3,300	65,000
	Total	55,300	20,400	3,300	79,000
1974–76	Right bank	0	9,800	0	9,800
	Left bank	0	0	0	0
	Islands	14,100	18,4000	32,500	
	Total	14,100	28,200	0	42,300
1976–78	Right bank	0	0	0	0
	Left bank	0	0	8,600	8,600
	Islands 0	38,000	1,800	39,800	
	Total	0	38,000	10,400	48,400
1978–79	Right bank	0	26,700	0	26,700
	Left bank	0	0	62,900	62,900
	Islands	0	90,700	156,800	247,500
	Total	0	117,400	219,700	337,100
1979–80	Right bank	0	0	0	0
	Left bank	0	0	0	0
	Islands	0	0	0	0
	Total	0	0	0	0
1980–82	Right bank	0	0	0	0
	Left bank	0	0	0	0
	Islands	0	0	0	0
	Total	0	0	0	0

Table 8. Average erosion rates.

Period	*Map sheet* 16-5	16-7	16-9	*Total reach*
1938–48	30,250	22,840	13,420	66,510 m^2/yr
	6,970	5,260	3,090	5,110 m^2/km yr
1948–61	30,010	18,450	38,350	87,510 m^2/yr
	6,910	4,250	8,840	6,730 m^2/km yr
1961–70	20,500	28,680	39,910	89,080 m^2/yr
	4,630	6,610	9,200	6,850 m^2/km yr
1970–74	26,020	28,010	14,700	68,720 m^2/yr
	5,990	6,450	3,390	5,280 m^2/km yr
1974–76	20,140	30,280	18,800	69,230 m^2/yr
	4,640	6,980	4,330	5,320 m^2/km yr
1976–78	21,900	28,000	12,700	62,600 m^2/yr
	5,050	6,450	2,930	4,810 m^2/km yr
1978–79	8,970	32,930	7,240	49,140 m^2/yr
	2,070	7,590	1,670	3,780 m^2/km yr
1979–80	77,680	48,260	17,830	143,780 m^2/yr
	17,900	11,120	4,110	11,050 m^2/km yr
1980–82	51,300	29,070	7,160	87,540 m^2/yr
	11,820	6,700	1,650	6,730 m^2/km yr

Table 9. Average deposition rates.

Period	*Map sheet* 16-5	16-7	16-9	*Total reach*
1938–48	4,410	2,040	3,480	9,930 m^2/yr
	1,020	470	800	760 m^2/km yr
1948–61	23,970	3,350	4,210	31,910 m^2/yr
	5,520	770	970	2,450 m^2/km yr
1961–70	60,680	28,210	15,880	104,770 m^2/yr
	3,980	6,500	3,660	8,050 m^2/km yr
1970–74	1,590	4,280	690	16,560 m^2/yr
	2,670	990	160	1,270 m^2/km yr
1974–76	9,930	19,860	0	29,800 m^2/yr
	2,290	4,580	0	2,290 m^2/km yr
1976–78	0	19,000	5,200	24,200 m^2/yr
	0	4,380	1,200	5,580 m^2/km yr
1978–79	0	116,720	101,210	290,600 m^2/yr
	0	26,890	23,320	22,340 m^2/km yr
1979–80	0	0	0	0 m^2/yr
	0	0	0	0 m^2/km yr
1980–82	0	0	0	0 m^2/yr
	0	0	0	0 m^2/km yr

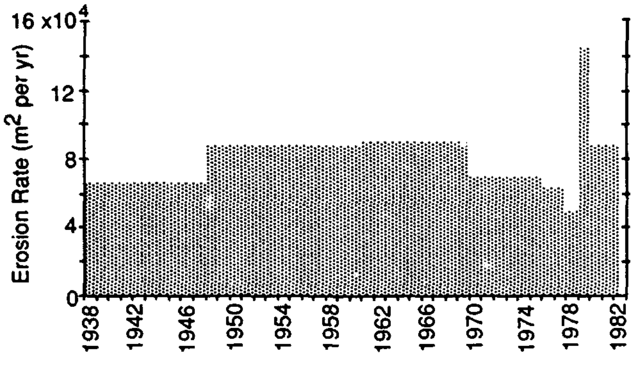


Figure 4. Average erosion rates for entire study area.

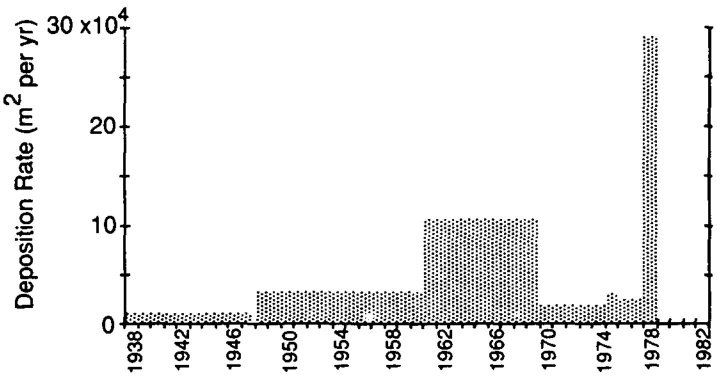


Figure 6. Average deposition rates for entire study area.

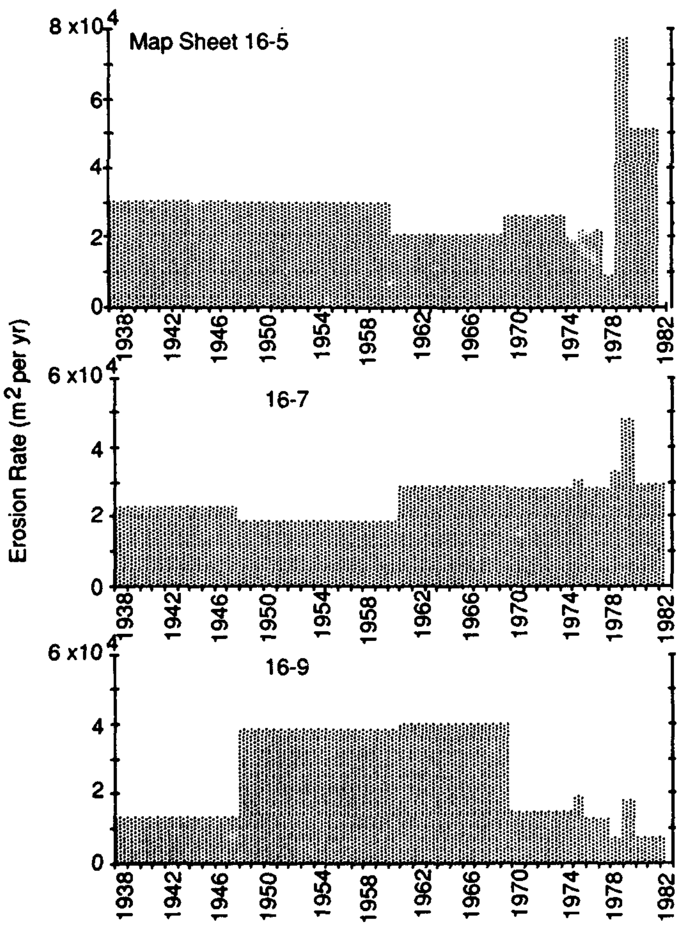


Figure 5. Average erosion rates for each map sheet.

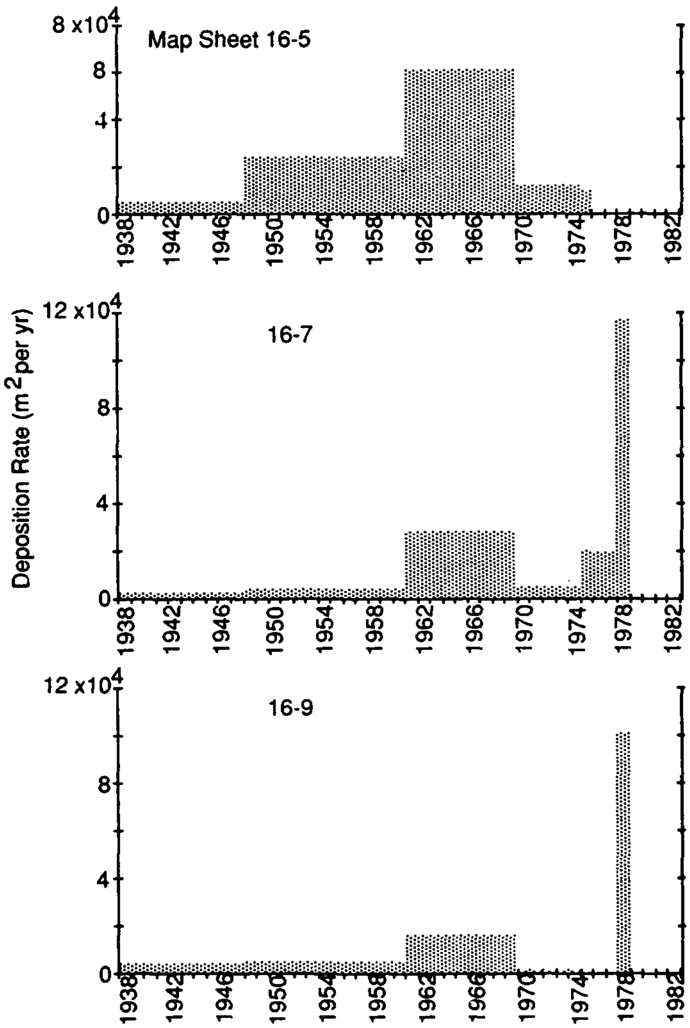


Figure 7. Average deposition rates for each map sheet.

1961–70 and period 1978–79. Figure 7 presents the same data for each individual map sheet. The deposition peak in period 1961–70 is highest on the downstream map sheet (map sheet 16-5) and decreases upstream. The deposition peak in period 1978–79 is confined entirely to the two upstream map sheets (map sheet 16-7 and 16-9) with no deposition occurring on the downstream map sheet.

In addition to examining average erosion and deposition rates for the entire study reach, each specific time period is also examined. Each of the following time period discussions presents total erosion or deposition measured during that specific period and discusses the various erosion rates calculated for that time frame. Any significant events or activities in the river during the time period that might affect or explain differences in erosion rates are noted.

Period 1938–48: 22 July 1938 to 4 June 1948

This period covers a total of 9.57 years. Total erosion over the three map sheets during period 1948–61 was 636,500 m^2. The long-term erosion rate is 66,510 m^2/yr for the entire study reach. Alternately, the average erosion rate is 5110 m^2/km yr. Over the entire stretch, erosion rates on the right bank averaged 2080 m^2/k yr; 2160 m^2/km yr for islands within the river; and 870 m^2 /km yr for the left bank.

The total deposition over the entire 13.01-km-long study reach during this period was 95,000 m^2, for an average deposition rate of 9930 m^2/yr. The deposition rate is only 15% of the erosion rate during the same period. Almost all of the deposition occurred among the in-river islands and along the right bank.

In addition to calculating erosion rates averaged over the total study reach, rates were calculated for each of the three map sheets. Average erosion rates varied from 8840 m^2/km yr for map sheet 16-9, (the map sheet covering the 4.34-km section of the river upstream of Goose Island); 4250 m^2/km yr for map sheet 16-7; and 6640 m^2/km yr for the downstream map sheet 16-5.

Period 1948–61: 4 June 1948 to 1 May 1961

This period covers a total of 12.81 years. Total erosion over the three map sheets during period 1948–61 was 1,112,100 m^2. The long-term erosion rate is 87,510 m^2/yr for the entire study reach. Alternately, the average erosion rate is 6730 m^2/km yr. Over the entire stretch, erosion rates on the right bank averaged 2540 m^2/km yr; 2340 m^2/km yr for islands within the river; and 1790 m^2/km yr for the left bank.

The total deposition over the entire 13.01-km-long study reach during this period was 403,800 m^2, for an average deposition rate of 31,520 m^2/yr. This amount is less than half the total erosion that occurred during the same period. Almost all of the deposition occurred along the left bank and among the in-river islands.

Erosion for each of the three map sheets varied from 236,400 to 491,300 m^2, for average erosion rates of 8840 m^2/km yr for the upstream map sheet 16-9, 4250 m^2/km yr for map sheet 16-7; and 6,910 m^2/km yr for the downstream map sheet 16-5.

Period 1961–70: 1 May 1961 to 12 May 1970

This period covers 9.07 years. Total erosion during period 1961–70 for the entire study reach was 89,080 m^2. The average erosion rate is 8908 m^2/yr. Alternatively, the data reveal erosion of 6850 m^2/km yr averaged over the 13.01-km length of the study area. These rates are almost identical to the erosion rate for the previous time period. Average erosion rates on the right bank were elevated over the previous time period, averaging 3170 m^2/km yr. Average erosion rates for islands within the river were 2080 m^2/km yr and rates for the left bank were 1600 m^2/km yr.

Total deposition during this period was 950,300 m^2, for an average rate of 104,7700 m^2/yr. This deposition is a considerable increase from the prior time periods. Much of this increase in deposition, at least for the downstream map sheet, can be attributed to the abandonment and filling in of several channels near the downstream end of the study area. This abandonment is linked to the blocking of several side channels of the Tanana near the Fairbanks International Airport (located outside of the study area) during the 1960s.

Deposition data for the period 1961–70 show a peak on each map sheet as readily seen on Figure 7. Much of the peak in map sheet 16-5 can be explained by the obstruction of side channels downstream of the study area, as discussed above. However, the side channel obstructions do not explain all of the upstream deposition. The 1967 flood occurred during this time period. Perhaps coincidentally, the 1970 photography bracketing the end of this time period was taken three years after the flood. Three years is the same length of time required for deposition areas to be identified after the blocking of the channel at Goose Island. This length of time was required for vegetation to became established, allowing the deposition areas to be identified. Part of the increased deposition visible in 1970 may include areas of deposition caused by the flood in 1967 that were beginning to establish vegetation by 1970. Additionally, flood levels in the Tanana were higher near the confluence of the Chena and decreased in magnitude upstream of the confluence (Fig. A4 in U.S. Army Corps of Engineers 1972a); this coincides with the decrease in deposition upstream on each of the three map sheets.

In contrast to the deposition rates, there is no significant increase in erosion rates during the same time period (1961–1970) that may be related to the flood event. The lack of erosion rate increase may indicate that a large and historically significant flood can have a greater impact on buildup of the floodplain by overbank sedimentation than an impact on increased erosion during the flood event. If this is true then deposition from irregular large flood events may tend to counterbalance the more routine and almost continuous erosion events.

Period 1970–74: 12 May 1970 to 19 Sept 1974

This period covers 4.71 years. Total erosion during this period was 327,800 m^2, with an average erosion rate of 68,720 m^2/yr. The data reveal a rate of 5280 m^2/km yr averaged over the 13.0-km length of the study area. These rates are slightly reduced from the two previous time periods. Average erosion rates on the right bank were 2160 m^2/km yr; average erosion rates for islands within the river were 1880 m^2/km yr; and average erosion rates on the left bank were 1240 m^2/km yr. Total deposition during this time period for the entire study reach was 79,000 m^2 or 16,770 m^2/year.

Average rates 1938–1974

Average erosion rates for the 13.01-km study reach of the river over the 36.22-year time span of the four periods prior to the 1975 construction were 79,640 m^2/yr or 6120 m^2/km yr. Average erosion rates for the right bank during this time span was 32,850 m^2/yr or 2530 m^2/km yr; the erosion rates for islands were 34,040 m^2/yr or 2620 m^2/km yr, and the erosion rates for the left bank was 18,570 m^2/yr or 1430 m^2/km yr. Average deposition rates for the entire study reach over the same time span was 42,190 m^2/yr, approximately 53% of the erosion rate for the same time span.

Period 1974–76: 19 Sept 1974 to 4 June 1976

This period covers a total of 1.42 years. The major in-river construction obstructing river flow occurred during this time period. In November 1975 the construction of the causeway between the right bank of the Tanana and Goose Island, located in the center of the river, blocked off the large right channel north of Goose Island. The entire river flow was forced into the narrower channel south of Goose Island. This constriction of the river reduced its width by two-thirds, from 1140 m of total channel width to 310 m.

Following construction of the causeway, the main river flow passed around Goose Island in the south channel. It turned north around the western end of Goose Island, returning to the north channel through connecting channels between Goose Island and Haines Island.

The diversion of the entire river's flow into the south channel caused a number of changes in the river system as the river readjusted. The initial response of the river was the removal of many of the in-channel bars in the south channel as the river scoured and increased its channel cross-sectional area to accommodate the increased flow.

During the spring of 1976, the main flow of the river swung around Goose Island and then turned sharply against the north bank as the flow reentered the north channel. Large areas of low, unvegetated to partially vegetated gravel bars in this bend (located at the edge of maps sheets 16-5 and 16-7) began to be eroded during that spring. A total of 30,000 m^2 of bars was eroded from the bend by 4 June 1976. This erosion was not included in the erosion figures calculated for the period since it was not part of the riverbanks by the definition adapted for this study.

Bank erosion in period 1974–76 for the whole study reach totaled 98,300 m^2. Average bank erosion rates totaled 69,230 m^2/yr. In other words, the data reveal erosion rates of 5320 m^2/km yr averaged over the 13.01-km length of the study area. These rates are actually slightly lower than the prior 36.22-year long-term erosion rate.

Erosion rates were also calculated for each of the three map sheets. The upstream map sheet 16-9 had a total erosion of 26,700 m^2 or 4330 m^2/km yr. For map sheet 16-7, total erosion was 43,000 m^2, or 6980 m^2/km yr; this is a slightly elevated rate of erosion. Much of that erosion, 35,600 m^2, occurred from islands within the river as the south channel and associated connecting channels started to enlarge. For map sheet 16-5, the area downstream of Goose Island, total erosion was 28,600 m^2, with an average erosion rate of 4640 m^2/km yr.

Total deposition over the entire study reach during this time period was 42,300 m^2. This results in a deposition rate of 29,800 m^2/yr.

Period 1976–78: 4 June 1976 to 4 June 1978

During this 2.00-year period the main river flow continued around Goose Island in the south channel and then flowed due north bending sharply back into the north channel. Erosion continued in the large areas of low, unvegetated to partially vegetated gravel bars in this bend. Approximately 75,000 m^2 of gravel bars was eroded. Again, this erosion was not included in the erosion figures calculated for the period (for the same reasons as for the last period).

During the winter of 1977–1978 a second causeway was built from the north shore of the Tanana to Goose Island. This causeway crossed the blocked, abandoned north channel of the Tanana to the western end of Goose Island. It did not have any effect on river flow.

Total erosion of riverbanks over the entire stretch during this period was 125,200 m^2. The average erosion rate is 62,600 m^2/yr. This provides an erosion rate of 4810 m^2/km yr averaged over the 13.01-km length of the study area.

Rates were calculated for each of the three map sheets. Map sheet 16-9 continued to show decreased erosion rates compared to the other two sheets, with an average erosion rate of 2930 m^2/km yr. These rates continue the trend of reduced erosion upstream of the constriction in the river caused by the Goose Island causeway. Map sheet 16-7 had the highest average erosion rate of the three map sheets, with a rate of 6450 m^2/km yr. Map sheet 16-5 had an average erosion rate of 5050 m^2/km yr.

Total deposition over the study reach during this time period was 48,400 m^2 or 24,200 m^2/yr. Deposition in the downstream Map sheet 16-5 ceased completely.

Period 1978–79: 4 June 1978 to 3 July 1979

This period covers 1.16 years. During the early spring of 1979 the second, western causeway was extended from Goose Island to an unnamed island located southwest of Goose Island. The small island was subsequently used as a gravel source for construction of a portion of the Tanana River Levee. This causeway extension blocked one of the channels flowing from the channel south of Goose Island toward the north channel downstream of Goose Island. This blockage diverted part of the flow reentering the north channel downstream of Goose Island and reduced erosion along the right bank in map sheet 16-5. Upstream of the eastern causeway many channels near the north bank were abandoned or filled as deposition of sediment continued. This deposition process upstream of the constriction caused by the causeway was more readily apparent when willows and other vegetation became established on the raised bar surfaces.

Total erosion during this period was 57,000 m^2. The average erosion rate is 49,140 m^2/yr. This figure provides an erosion rate of 3,780 m^2/km yr, averaged over the 13.01-km length of the study area. Erosion upstream of Goose Island on map sheet 16-9 was at a very low level, with an average erosion rate of 1670 m^2/km yr, continuing the trend of reduced erosion and increased deposition upstream of the causeway. At 7590 m^2/km yr, average erosion rates in the middle reach (map sheet 16-7) were much higher; this result reflects the continued erosion of islands as channels enlarged in the vicinity of Goose Island. Average erosion rates for the downstream reach (map sheet 16-5) were also lower (at 2070 m^2/km yr) than the middle reach.

Total measured deposition over the study reach increased dramatically to 337,100 m^2. This is a rate of 290,600 m^2/yr and a 1200% increase over the previous period. The sudden peak actually reflects a gradual buildup of deposition upstream of the river construction with the area finally built to sufficient vertical height to allow establishment of vegetation and to allow measurement under the guidelines used in this study. The majority of the deposition occurred on map sheet 16-9, upstream of Goose Island, with the rest occurring on the eastern part of map sheet 16-7. The deposition areas on map sheets 16-9 and 16-7 are located upstream of the constriction of the river at Goose Island. No measurable deposition occurred on the western end of map sheet 16-7 and on map sheet 16-5 downstream of the constriction caused by the causeway.

Period 1979–80: 3 July 1979 to 7 May 1980

This period covers 0.69 years. Erosion during this time period was scattered throughout the study area. The presence of the causeway extension from Goose Island, blocking off a major channel leading from the south channel to the north channel, continued to redirect enough flow to reduce erosion on the right bank immediately downstream of Goose Island. Right bank average erosion rates for map sheet 16-7 were reduced from 4010 m^2/km yr for the prior time period to 2840 m^2/km yr for this time period. Erosion rates increased in the islands as the southern channels continued to increase in size.

Total erosion for the study area during this period was 99,200 m^2. The average erosion rate for this time period for the entire area was 143,780 m^2/yr. This results in an average rate of 11,050 m^2/km yr over the entire study reach. Erosion upstream of Goose Island on map sheet 16-9 continued at a lower level than on the other two map sheets, with an average erosion rate of 4110 m^2/km yr. In comparison, the average erosion rates for map sheets 16-7 and 16-5 were 11,120 and 17,900 m^2/km yr, respectively. Deposition was negligible during this period.

Period 1980–82: 7 May 1980 to 4 June 1982

This time period covers 2.15 years. During the spring of 1981 a major in-river construction and river realignment project occurred downstream of the study area near the Fairbanks International Airport at the airport erosion site. Erosion on the outside of a large bend of the Tanana threatened the railroad spur to the airport. A pilot channel was excavated during the winter across the neck of the bend. An extension of the Tanana Levee and a series of protective groins were built north of the pilot channel, across the bend, blocking it and diverting flow into the pilot channel. This series of river training structures, known as the "Phase III Levee Project," restricted the overall width of the river approximately 40% from the pre-construction width. However, the length of the river in this area was shortened considerably; this action steepened the water surface slope through this stretch. The effects of this steepening would be expected to affect the river upstream, within the lower part of the study area.

The extension of the western causeway from Goose Island to the small island located southwest was breached by the river in the early summer of 1981. While the resulting increased flow into the north channel increased erosion among the islands, no discernible erosion was measured along the right bank of the north channel downstream of Goose Island.

Total erosion for the entire study reach was 188,200 m^2. This provides an erosion rate of 87,540 m^2/yr. Erosion continued to be much lower on map sheet 16-9, averaging 1650 m^2/km yr. Erosion on map sheet 16-7 averaged 6700 m^2/km yr. All of the erosion occurred in the south channel, located south of Goose Island. Erosion rates averaged 11,820 m^2/km yr on map sheet 16-5. The bulk of the erosion occurred along the south bank and among the islands. This erosion rate was higher than the erosion rates found for the other two map sheets. It may reflect both continued erosion in the river channels downstream of the Goose Island river constriction and more significantly an increase in erosion due to the downstream river rechannelization with its localized increase in water surface slope. The average erosion rate for the total reach, 6730 m^2/km yr is comparable to the long-term average rate prior to the constriction of the river at Goose Island. It should be qualified that the erosion during this period is much less evenly divided among the three map sheets.

Table 10. Net balance of gain or loss of riverbank area.

Period	*Erosion* $(-m^2)$	*Deposition* $(+m^2)$	*Net gain (+) or loss (–) due to erosion and deposition*	
1938–48	636,500	95,000	–541,500	m^2
			–56,580	m^2/yr
1948–61	1,112,100	403,800	–708,300	m^2
			–55,290	m^2/yr
1961–70	808,000	950,300	+142,300	m^2
			+15,690	m^2/yr
1970–74	327,800	79,000	–248,800	m^2
			–52,160	m^2/yr
1974–76	98,300	42,300	–56,000	m^2
			–39,440	m^2/yr
1976–78	125,200	48,400	–76,800	m^2
			–38,400	m^2/yr
1978–79	57,000	337,100	+280,100	m^2
			+241,470	m^2/yr
1979–80	99,200	0	–99,200	m^2
			–143,770	m^2/yr
1980–82	188,200	0	–188,200	m^2
			–87,530	m^2/yr
Average Net Balance				
1938–74 (36.22 yr)			–1,356,300	m^2
			–37,450	m^2/yr
1974–82 (7.42 yr)			–140,100	m^2
			–18,880	m^2/yr

Average erosion rates 1974–1982

Average erosion over the total study reach during the last five time periods covering the 7.42 years since the construction of the causeway to Goose Island is 76,540 m^2/yr or 5880 m^2/km yr, only a 4% decrease in average yearly erosion over the four prior time periods from 1938 to 1974, well within the error margin of the analysis.

Net gain or loss of riverbank area

Table 10 summarizes the net loss or net gain of riverbank area for the 13.01-km study reach of the river. For every time period except two there is a net loss of riverbank area. Net loss occurs when the total erosion areas exceed the total deposition areas during the time period. The two positive time periods occurred in 1961–70 and 1978–79 when there were net gains of +142,300 m^2 and +298,100 m^2, respectively. As previously discussed, large areas of deposition were measured upstream of Goose Island during period 1978–79, with the buildup of these areas of deposition occurring over a longer time frame, but the buildup was only included in the measurements once the bar surface had been built up to a sufficient height to allow the establishment of vegetation. This distinguishes these areas from more active in-river bars.

The net balance of erosion vs deposition during the periods prior to the construction of the Goose Island causeway is negative. The findings average –37,450 m^2/yr over the entire study reach. The net balance during the periods following construction is smaller but also negative; they average –18,880 m^2/yr. Average net balance over the entire study period of 1938 through 1982 was a –1,496,400 m^2 or –34,290 m^2/yr.

If the net balance of erosion vs deposition of riverbank area is negative as determined from the aerial photography, then it can be expected that the surface area of the active river channel should increase. Three possible interpretations result. First, river braiding is increasing in this area as the river develops broader and more divided channels. Second, the buildup of depositional areas are cyclic due both to the time length required for vertical buildup of finer grained sediments and the establishment of vegetation; over time these cyclic episodes of buildup may balance out the areas of erosion. Finally, the photointerpretation process may not be sufficiently refined to accurately identify and measure deposition areas as they occur in the river.

The former channel area of the north channel downstream of the Goose Island causeway is not included in the depositional area data. However, this area was removed from the river system when the causeway was built across the north channel in 1975. The approximate total area removed from the active river channel was 1,500,000 m^2. If this amount is added to the total depositional area measured during the period of 1938 to 1982, then a net positive gain of 3400 m^2 of riverbank area results. In other words, there is a net removal of 3400 m^2 from the active river system. In that case, the total surface area of the active river system has decreased slightly, indicating that the river is narrower and less braided than it was in 1938.

Changes in water surface slopes

Water surface elevations have been collected at irregular intervals on the Tanana River since 1973. These data have generally been collected by personnel of the Water Resources Division, U.S. Geological Survey. A series of water surface elevation staff gauges, referred to as "T-sites," were established by the Corps of Engineers in 1973 at periodic intervals along the right bank of the Tanana River. The sites were initially established to provide water surface elevation data for the design of the Tanana River Levee. The location of the T-sites range from T1, just upstream of the mouth of the Chena River, to T15, 50 km upstream. Figures 1 and 2 indicate the location of the T-sites. Several of the T-sites have been destroyed over the years by river erosion and have not been replaced.

For active gravel-bottom streams, the surface width varies with both bankfull discharge and channel slope. If the surface width is reduced, the slope would be expected to increase in order to maintain the same discharge. The river obtains this local slope increase by deposition of material upstream of the constriction and local scour or removal of material downstream of the constriction (Chang 1980).

Table 11 lists the water surface elevations in the vicinity of Goose Island for five years between 1973 and 1982 and Figure 8 plots the water surface elevations. Site T5 is located 17 km above the confluence with the Chena and 7.5 km upstream of Goose Island. Site T4 is 14 km upstream of the confluence Site T3 is 9.1 km upstream of the confluence, on the south channel southwest of Goose Island. Site T2 is 7.6 km upstream of the confluence, downstream of Goose Island on the right bank. Site T1 is located approximately another 5 km downstream, outside the study area.

Table 11. Water surface elevations (in meters) at T sites.

Year	*T5*	*T4*	*T3*	*T2*	*T1*
1973	138.18	135.74	132.26	130.74	128.42
1975	138.39	135.32	132.77	131.44	128.89
1980	137.95	135.07	132.37	131.00	128.36
1981	138.01	135.54	135.50	131.19	128.74
1982	138.07	135.52	132.17	131.03	128.60

1973: Average of 9 readings, Av. Q= 1,400 m^3/s
1975: 7/25/75 Q = 1,720 m^3/s
1980: Average of 3 readings, Av. Q= 1,247 m^3/s
1981: Average of 2 readings, Av. Q= 1,440 m^3/s
1982: Average of 3 readings, Av. Q= 1,323 m^3/s

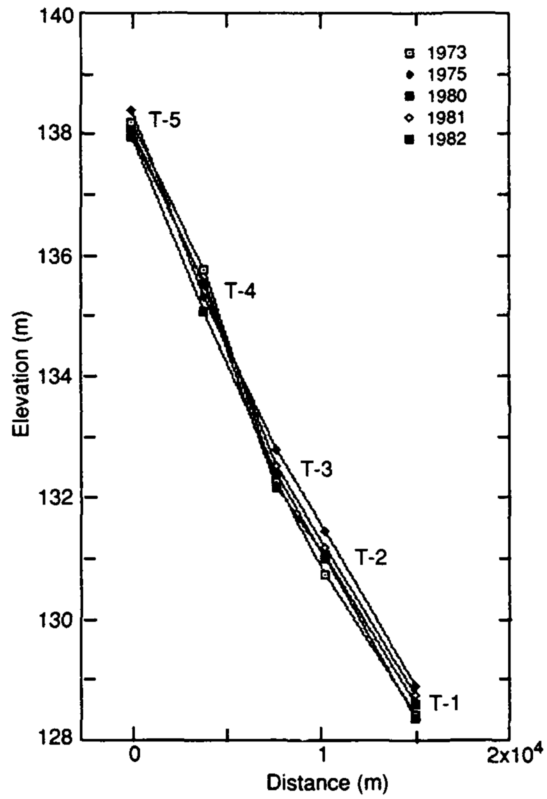


Figure 8. Plot of water surface elevations in vicinity of Goose Island.

A slight increase in the water stage levels began in 1980 at T4 with a corresponding decrease in water stage levels at T3. These data reflect the aggradation of bars upstream of the river constriction at the Goose Island causeway and a scouring in the south channel flowing around Goose Island.

Table 12 lists corresponding water surface slopes in the vicinity of Goose Island. It displays the increase in slope over time between T4 and T3 and the decrease in slope between T3 and T2.

Table 12. Water surface slopes in the vicinity of Goose Island.

Year	*T4 to T3* 3,900 m	*T3 to T2* 2,500 m	*Number of readings*	*Average* Q
1973	0.00063	0.00057	9	1400 m^3/s
1975	0.00065	0.00053	1	1770 m^3/s
1980	0.00069	0.00055	3	1247 m^3/s
1981	0.00078	0.00053	2	1440 m^3/s
1982	0.00083	0.00047	3	1323 m^3/s

River cross section comparisons

Four cross sections within the study reach were compared to the data generated by the airphoto analysis. This procedure was initiated to evaluate the accuracy of airphoto analysis in terms of timing of erosion and changes in channel cross section. The four cross sections, labeled FNSB1, FNSB2, FNSB3, and FNSB4, were originally established by the Fairbanks North Star Borough to study impacts of gravel removal from the river at the south side of Goose Island. Surveys were conducted in 1977 and 1979 by Stutzman Engineering for the Borough, and in 1980 and 1981 by the Alaska District, Corps of Engineers. These four cross sections were the only ones within the study area surveyed more than once or twice during the study period.

Figure 2, the photomosaic of the study area provides the relative locations of each of the four cross sections. FNSB1 is located downstream of Goose Island, 7.6 km above the confluence of the Chena. FNSB2 is located across the south channel southwest of Goose Island, 9.1 km above the confluence. FNSB3 is located upstream of Goose Island past the main deposition area just upstream of the causeway, 12 km above the confluence. FNSB4 is located 2 km upstream of FNSB3 near the downstream end of Meridian Island, 14 km above the confluence.

Figure 9 graphs the elevations of a portion of cross section FNSB1. This portion of the cross section crosses the small south channel between Haines Island and the left bank. The surveys show the increase in cross-sectional area over time as the channel deepens as well as widens following construction of the Goose Island causeway. The in-river bar present in 1977 had completely disappeared by 1979. Cross-sectional area of the channel increased steadily from 350 m^2 in 1977, to 411 m^2 in 1979, to 510 m^2 in 1980. By 1981, the channel appeared to have reached equilibrium and had actually decreased in cross-sectional area to 450 m^2. North and south bank lines of the channel did not erode to any discernible degree throughout this time. This indicates that the bed materials in the channel are more erodible than the bank materials.

Figure 10 graphs the elevations of the northern portion of cross section FNSB1, north of Haines Island.

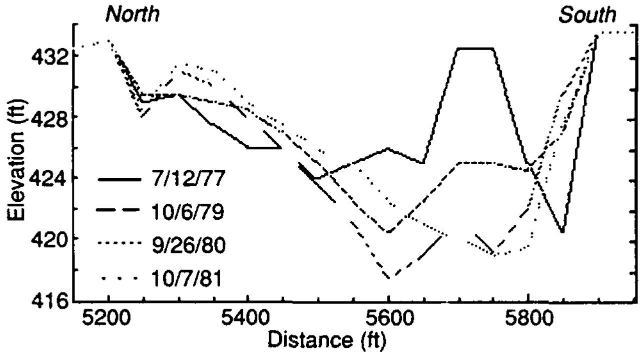


Figure 9. Southern portion of cross section FNSB1.

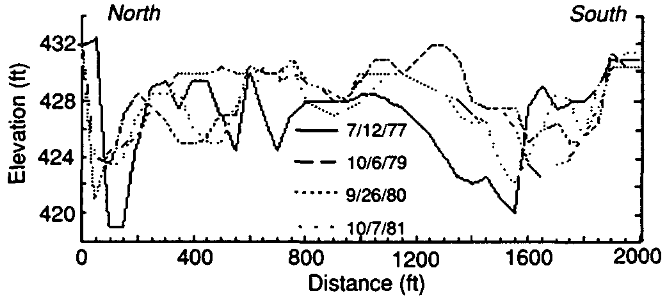


Figure 10. Northern portion of cross section FNSB1.

The channel in this portion of the cross section decreased in cross-sectional area between 1977 and 1979 from 554 m^2 to 382 m^2. The cross-sectional area stayed approximately the same in 1980 at 392 m^2. By October 1981 the cross-sectional area had increased to 471 m^2. The increase in cross-sectional area in 1981 followed the breaching of a small causeway connecting an unnamed island southwest of Goose Island with Goose Island, which diverted more flow back into the north channel downstream of Goose Island.

Figure 11 graphs the elevations of cross section FNS B2 located south of Goose Island and upstream of FNSB1. The surveys show the channel cross section increasing in area each year from 1977 to 1980. While the increase in the south channel cross section was mainly by scouring, some erosion of the south bank and widening of the channel also occurred between 1980 and 1981. The smaller channel to the north also increased in cross section until 1981. Cross-sectional areas of the channels totaled 494 m^2 in 1977, 549 m^2 in 1979, and 649 m^2 in 1980. In 1981 part of the flow in the north channel was diverted north around the small island that makes up the north edge of this cross section when a small causeway connecting this unnamed island with Goose Island was breached. The small north channel shown in the cross section partially filled in and the total cross section area in 1981 was reduced to 527 m^2. Bank erosion or recession of 50 ft (15 m) in one year between 1980 and 1981

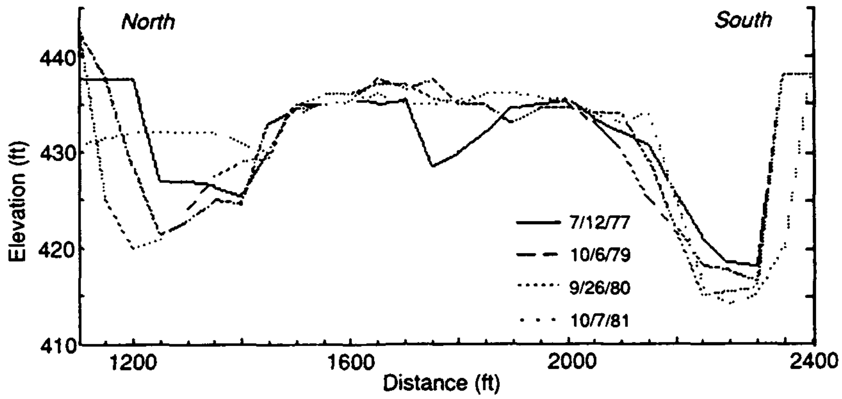


Figure 11. Cross section FNSB2.

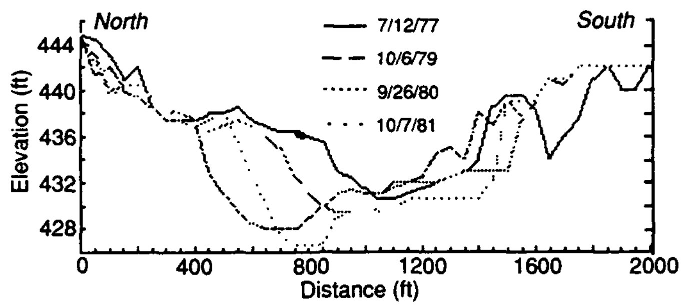


Figure 12. Cross section FNSB3.

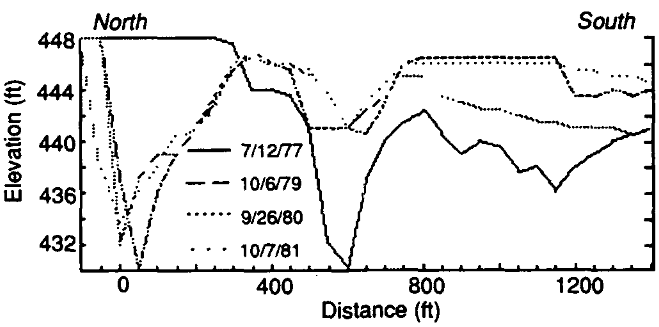


Figure 13. Northern portion of cross section FNSB4.

was measured along the south bank. Bank recessions of 50 ft (15 m) between 1977 and 1979, 32 ft (10 m) between 1979 and 1980, and greater than 70 ft (21 m) between 1980 and 1981 were measured along the northern end of the cross section.

Figure 12 graphs the elevations of cross section FNS B3 located upstream of Goose Island. While the surveys show the main channel shifting to the north over time and some deposition along the south bank, only minor changes in the position of the north bank line occurred. The cross section is located too far upstream to show the large areas of deposition and channel abandonment just upstream of Goose Island and the causeway. This illustrates the problems of establishing sufficient river cross sections at sufficiently close spacings to accurately monitor river system changes. Cross-sectional areas increased from 514 m^2 in 1977 to 626 m^2 in 1979. The cross-sectional area decreased to 563 m^2 in 1980 and increased again to 649 m^2 in 1981. Total bank recession on the right or north bank from 1977 to 1979 was 15 m.

Figure 13 graphs the elevations of a portion of cross section FNSB4 located upstream of cross section FNSB3. At this cross section a meander bend of the main channel shifted north and eroded 106 m of the north bank over a four-year period. Almost 90 m of that erosion occurred between 1977 and 1979. Changes in cross-sectional area during the four years were variable, reflecting the northward migration of the channel thalweg and the filling in of the channel behind it. Cross-sectional areas decreased from 714 m^2 in 1977 to 361 m^2 in 1979. The area increased again to 592 m^2 in 1980 but decreased yet again to 393 m^2 in 1981. Decreases in cross-sectional areas within this portion of the cross section were balanced by changes in other portions of the cross section located further south and not shown here. However, the result is that there was no real pattern of any net increase or decrease in cross-sectional area over time.

Topologic analysis

The prior erosion analysis raises the question of whether the Tanana River braiding has increased or decreased over time. In order to examine this question, a different method of airphoto analysis was attempted. Several researchers have used various topologic analysis techniques to quantify properties of river systems; geomorphic topologic analysis as applied to streams examines the spatial relationship of individual channel segments and junctions of stream networks (Shreve 1967, Mock 1976). Through use of topologic analysis techniques, numerical data are derived from airphotos or maps. This allows a quantitative, systematic analysis of the photographs that may reveal trends not readily apparent in the photographs themselves. Howard et al. (1970) compared interrelationships between properties of 26 braided streams. Smart and Maruzzi (1972) compared quantitative properties of delta channel networks using somewhat similar methods.

In addition to use of topologic analysis to compare different streams, use of this analysis to examine changes over time within a single stream is helpful. This study utilizes the techniques and parameters outlined by Howard et al. (1970) to analyze photography of the Tanana River taken in three, widely separate years. Because reliable historical information on long-term trends in hydrology and hydraulic parameters is lacking for the Tanana, this topologic analysis may provide new information on river response over time to such activities as channel obstruction and in-river construction.

Three sets of airphotos from different years were selected for analysis. The sets are dated 1938, 1970 and 1982 and each of these dates was selected for a particular reason. The 1938 photographs are the earliest available for the study site on the Tanana River and also are the earliest used in the prior erosion analysis. The 1970 photo set was taken prior to major man-made interferences in the river in the vicinity of the Fairbanks International Airport just upstream from the confluence of the Chena River. The 1982 period coincides with the last analysis period of the erosion study. The lower reach of the 1982 photo set covers the major river rechannelization near the Fairbanks International Airport, which occurred in 1981. All three sets of photographs cover the Tanana River from the lower end of Meridian Island downstream, past Goose Island and the mouth of the Chena River, to Byers Island; the photos covered a total reach of approximately 13 km.

All three sets of photos were of a nominal scale of 1:12,000. Approximately 20 photographs were required for each year's mosaic. The 1938 photomosaic is a full size positive transparency made from the mosaicked original photos. All three sets of air photographs were taken at moderately low flow levels, approximately 850 m^3/s or less.

A separate Mylar overlay was prepared for each mosaic. The centerline of all major active channels was traced onto the overlay, forming a network of intersecting and dividing channels. The identification of channels to be marked in any such study is dependent on the scale of the photographs, the stage level of the river and the subjective judgment of the interpreter. As long as the same subjective judgment is applied consistently to all photomosaics being analyzed, the results are comparable between mosaics.

In this study, the identification of active channels was based on size, appearance and apparent active channel flow. Any active channel greater than approximately 10 m in width (which represents approximately 1 mm on the photograph) was marked. A number of small channels cut across the surface of bars but were not continuous or actively flowing at that river stage level; these were not marked as active channels.

The river reach on each mosaic was then divided into six evenly divided sections. Each of these sections is 2.17 km long. Following the methods of Howard et al. (1970), each section is twice as long as the approximate average river width throughout the reach. A centerline for each section was also marked. For each section, several parameters were measured and calculated. A channel segment is the line segment between any two junctions or bifurcations of a channel. The number of channel segments are then used to calculate two parameters, N and E, where E is the braiding index which is the average number of channel segments bisected by the end lines and center line of a section and N is the total number of channel segments totally within the section and entering the section from upstream. Channel segments leaving the section are counted in the next section downstream or, in the case of the last section, not counted.

The largest or widest channel identifiable on the airphotos is designated the main channel and marked on the overlay. The length of the main channel as well as the straight line distance between the upstream and downstream ends of the main channel were measured. The sinuosity value is the ratio of these two lengths:

$$U = \frac{\text{length of main channel}}{\text{length of reach}}. \quad (2)$$

This value is *not* the same as the sinuosity value for the river as a whole. When the Tanana River is near bankfull flow, the majority of the in-river bars dividing individual channels are underwater and the river has a straighter pattern (or lower sinuosity) than the individual main channels within the river system.

The channel networks derived from the photomosaics for each of the three years are shown in Figure B4. The parameters measured from the three channel networks are shown in Table 13. Comparing the 1938 and the 1970 averages for the total river reach indicates that the braiding index E has decreased substantially from 1938 to 1970. The total number of channel segments N has also decreased; the river reach in 1970 is less braided than in 1938. Examining individual sections, it is apparent that most of the decrease in braiding has occurred in the two most downstream sections.

The average braiding index E and total number of channel segments N for the total river reach also decreased between 1970 and 1982. However, within the reach, the values for the individual sections vary considerably. These findings reflect the substantial man-made interferences in the river since 1970. Two major in-river construction projects that caused constrictions in the river manifest themselves as changes in either the E or N values. The findings reflect both a decrease in braiding within the immediate section where the constriction occurs, and an increase in braiding within the sections both immediately upstream and downstream of the constriction. These findings suggest that the river adjusts in both directions to a change in the river equilibrium.

Table 13. Measured topologic parameters from Tanana River photomosaics.

Section	*Parameter*	*1938*	*1970*	*1982*
1	*E*	4.67	5.33	3.33
	N	19	23	19
2	*E*	6.33	4.33	2.33
	N	32	21	4
3	*E*	4.00	4.00	3.67
	N	8	9	13
4	*E*	3.67	3.33	3.00
	N	14	16	15
5	*E*	3.67	2.00	1.67
	N	18	7	7
6	*E*	4.00	1.67	1.67
	N	19	7	9
For total river reach				
Average	*E*	4.39	3.44	2.61
Total	*N*	110	83	67
Length of reach (m)		13,080	13,080	13,080
Length of main channel (m)		16,970	16,636	16,735
Sinuosity *U*		1.30	1.27	1.28

E = braiding index
N = channel segments

The Goose Island causeway, which blocked the north channel and reduced the overall channel width of the river 60% when constructed in 1975, is located in Section 2. As indicated in Table 13, the braiding index reduced to 2.33 (in 1982) from 4.33 (in 1970) and total number of channel segments reduced from 21 to 4. This result is consistent with expectations following the obstruction of a major channel within a segment. Upstream N values decreased slightly, changing from 24 to 19 and increased from 9 to 13 downstream. Braiding indices decreased from 5.33 to 3.33 upstream and from 4.00 to 3.67 downstream. This finding indicates that the river may have tried to maintain its equilibrium by increasing the number of channels on either side of the constriction.

The Phase III levee and groin system near the Fairbanks International Airport, which blocked a large river bend and moved the river south into a new pilot channel in the spring of 1981, is located in Section 5. This series of river training structures restricted the overall width of the river approximately 40%. Although the braiding index of the section decreased in 1982, the total number of channel segments stayed the same. Upstream the number of channel segments decreased from 16 to 15 and downstream increased from 7 to 9.

The measured parameters for the total reach showed a substantial decrease in the braiding index over the years from 4.39 in 1938, to 3.44 in 1970, and to 2.61 in 1982. The total number of channel segments also decreased substantially from 110 in 1938 to 67 in 1982. This would indicate a substantial decrease in total braiding of the river since 1938.

Based on 26 braided streams throughout the United States, Howard et al. (1970) derive several relationships between braiding parameters and hydraulic and hydrologic parameters. One equation relates slope to the braiding index and several other hydraulic parameters:

$$G = 0.21\, D^{0.16}\, Q_f^{\,-0.52}\, E_i^{\,0.24} \qquad (3)$$

where G = gradient or slope
D = the median grain size of channel bed in millimeters
Q_f = mean annual flood
E_i = E–1 where E is the braiding index.

For the case of the Tanana River within this reach:

D = 8 mm in 1981 (Burrows and Harrold 1983)
Q_f = 2550 m^3/s
E_i = 2.61–1 = 1.61.

Table 14. 1982 slope and braiding parameters.

Section	E	N	Slope
1	3.30	28	0.00069
2	2.33	4	0.00106
3	3.67	13	0.00041
4	3.00	19	0.00047
5	1.67	3	0.00057
6	1.67	18	0.00043
Total reach	2.61		0.00054

Substituting the values for D, Q_f, and E_i into eq 4.1 results in a slope of 0.00093, which is not quite twice as steep as the average measured slope of 0.00054 for the river reach. Substituting the braiding index from 1938, which would represent a more undisturbed condition, results in a calculated slope of 0.0011. Additional work may refine this equation to better fit the conditions encountered in Tanana River with its substantial amount of man-made interferences within this reach. Use of a future derivative of this equation may allow estimation of either gradient or other parameters from historical aerial photography in the absence of field data.

The slope values surveyed in the summer of 1982 (Table 14) were compared to the braiding parameters obtained from the 1982 mosaic (Table 13) and plotted in Figure 14. This plot shows that there is no correlation between the braiding index and the slope within this modified stretch of the Tanana River. Where there are constrictions in the river and the braiding has been decreased by channel blockage and rerouting, local slope has actually increased. This finding differs from the relationship between braiding and average river slope over a long distance where increased braiding is correlated with a higher slope upstream of North Pole and decreased braiding is correlated with a lower slope downstream of Goose Island.

SUMMARY AND CONCLUSIONS

A 13-km length of the Tanana River centered on Goose Island is the study site of this report. The Tanana River is a gravel, braided, multichannel river carrying a large suspended sediment load. This area was selected because it is the location of a causeway constructed in 1975 that obstructs a major channel of the Tanana River. Since construction of the causeway occurred prior to any in-river construction associated with the Tanana River Flood Control Levee, analysis of this particular site provides insights regarding the response of a large river system to major intrusion into its channel affecting flow regime.

In the immediate vicinity of Goose Island, the Tanana River is composed of two main channels, located on either side of Goose Island and several smaller associated islands. Constructed in late 1975, a causeway (825 m in length x 12 m in width) extends due south from the north bank of the Tanana to the upstream end of Goose Island. The causeway completely obstructs the north channel of the Tanana River, diverts flow into the south channel, and reduces the active river width to 300 m in a single channel (from a combined width prior to construction of 1150 m). The constriction in the river caused by the causeway has affected both the upstream and downstream morphology of the river.

Ten sets of historical airphotos were used to analyze long-term morphometric changes in the river over nine consecutive time periods. The time periods began in 1938 and ended in 1982. The length of each time period was calculated by use of the "effective erosion year" concept; this concept is based upon the premise that the vast majority of river erosion occurs during a 6-month open water period.

Airphoto analysis identifies erosion of riverbanks and allows monitoring of erosion over large areas. To replicate equivalent data by field surveying would be difficult and expensive. However, the method does not

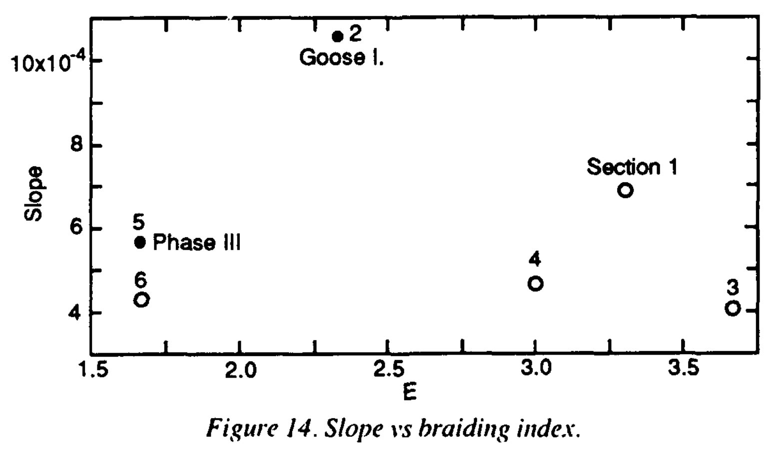


Figure 14. Slope vs braiding index.

identify erosion of in-river gravel bars or changes in channel cross-sectional areas. The stage of the river when the photos were taken affects the identification of in-channel features.

The airphoto analysis is not successful in specifying time of deposition during periods of large sediment buildup; this weakness in the technique arises due to the time lag required for vegetation to establish on newly aggraded bar surfaces. Identification of vegetation on bar surfaces is required to differentiate these newly built-up areas from ephemeral bar surfaces.

During the analysis of the construction impacts of the Goose Island causeway upon the river system, a number of effects possibly attributed to the obstruction of the north channel were noted. Erosion data, averaged over the entire study reach, were not significantly different for the time periods following the causeway construction compared to the time periods prior to construction. More localized erosion rates based on each map sheet and examining localized differences in right bank vs left bank vs island erosion displayed significant short-term differences in pre- vs post-construction time periods.

During post-construction, erosion was generally localized in south channels and islands downstream of the river constriction resulting from the causeway. A noticeable decrease in erosion upstream of the causeway was also noted.

Deposition upstream of the river constriction was dramatic. Measurement of this deposition was delayed several years due to methodology used to identify the deposition. If a standard and repeatable method could be derived to identify and measure areas undergoing local aggradation, then the potential of the photo method would be greatly enhanced for monitoring in-river construction effects.

Based on elevated erosion rates downstream of Goose Island on map sheet 16-5, the construction activity continued to impact erosion during 1980–82, the last time period monitored. However, the construction of the Phase III river alignment project in the spring of 1981, with the realignment of the meandering bend and localized steepening of the river, had the potential of increasing erosion upstream and thus affecting measurements within the downstream portion of the study area.

Based on erosion data from just downstream of Goose Island, located on map sheet 16-7, erosion peaked in 1979–80. Erosion rates then returned to near long-term averages in 1980–82. Erosion upstream of Goose Island continued far below long-term averages through 1982, indicating that the downstream constriction continued to affect erosion rates in this area.

Examination of the deposition data shows that the deposition upstream of Goose Island peaked in 1978–1979. No noticeable deposition has occurred since that time. Downstream, no measurable deposition occurred after 1974–76 when causeway construction was completed. The lack of deposition since 1976 is speculated to be caused by increased channel slope due to the construction of the causeway at Goose Island. After 1981 the lack of deposition may be caused by increased erosion and Phase III construction downstream of the study area.

Water surface slope data, which are independently collected field data, verified results of airphoto interpretations. The water surface elevation data indicate that following construction of the causeway, the water surface slope increased in the vicinity of Goose Island and decreased upstream of Goose Island. This adjustment in slope continued unchanged through 1982. In addition slope data downstream displayed an increase after 1981 as Phase III altered the downstream portion of the study area. These data are consistent with trends in deposition and erosion both upstream and downstream of Goose Island during the same time frame.

Four cross sections with multiple years of data were available within the study area and were used as independently collected field data to compare with results of the aerial photography interpretation study. Time and cost considerations limit both the number of cross sections and the number of times a cross section can be surveyed. Cross sections were generally too separated to allow realistic estimates of erosion or deposition along a riverbank. The physical spacing of cross sections often misses critical areas. For example, FNSB2 and FNSB3 are located on either side of the large area of deposition and bar buildup upstream of Goose Island. The surveys of these two cross sections do not indicate the large deposition that took place upstream of the causeway.

The topologic analysis was a readily usable method that quantified changes in braiding over time using three different years of aerial photography. It showed a strong decrease in braiding between 1938 and 1982. However, the relationships originally developed by Howard et al. (1970) correlating the braiding index with water surface slope did not work well for the modified stretch of the Tanana River studied here. In fact, there was an inverse relationship between increased slope and decreased braiding in the sections of river where in-river construction had occurred. The river was constricted in those locations and the water surface slope locally increased.

In summary, the Tanana River had returned to near equilibrium by 1980, five years after the construction of the Goose Island causeway. However, some effects from this constriction of the river were documented in 1982. Because of additional in-river construction downstream of the study area in 1981 which affected upstream areas in 1982, the separate effects from the Goose Island causeway cannot be monitored beyond 1982.

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APPENDIX A: EROSION AND DEPOSITION DATA

Table A1. Flood frequency analysis.

15485500 TANANA RIVER AT FAIRBANKS

YEAR	DATA	ORDERED	RANK	PROB.	RET. PERIOD
1973	62800.0	96400.0	1	.049	20.395
1974	59400.0	88000.0	2	.114	8.807
1975	68300.0	87700.0	3	.178	5.616
1976	53000.0	78000.0	4	.243	4.122
1977	62900.0	75100.0	5	.307	3.256
1978	60200.0	73100.0	6	.372	2.691
1979	75100.0	70400.0	7	.436	2.293
1980	60500.0	68300.0	8	.501	1.997
1981	66100.0	66100.0	9	.565	1.769
1982	70400.0	62900.0	10	.630	1.588
1983	73100.0	62800.0	11	.694	1.441
1984	87700.0	60500.0	12	.759	1.318
1985	78000.0	60200.0	13	.823	1.215
1986	96400.0	59400.0	14	.888	1.126
1987	88000.0	53000.0	15	.952	1.050

15485500 TANANA RIVER AT FAIRBANKS

```
     SAMPLE STATISTICS
MEAN =    70793.          S.D. =   12342.1          C.S. =     .7308          C.K. =    3.5603
     SAMPLE STATISTICS (LOGS)
MEAN =   11.1539          S.D. =     .1689          C.S. =     .4355          C.K. =    3.2604
SAMPLE MIN =  53000.    SAMPLE MAX =  96400.     N =  15
PARAMETERS FOR GUMBEL I      A =  .000107     U =    65264.
PARAMETERS FOR LOGNORMAL      M = 11.1539     S =  .1689
PARAMETERS FOR THREE PARAMETER LOGNORMAL      A =   41233.     M = 10.2131      S =  .4206
     STATISTICS OF LOG(X-A)
MEAN =   10.2131          S.D. =     .4206          C.S. =   -.0824          C.K. =    3.4635
PARAMETERS FOR LOG PEARSON III BY MOMENTS      A =  .0368     B = .21090+02   LOG(M) =10.3781     M =   .32150+05
PARAMETERS FOR LOG PEARSON III BY MAXIMUM LIKELIHOOD    A =  .0615    B = .73050+01   LOG(M) =10.7044    M =  .44
DISTRIBUTION STATISTICS     MEAN = 11.1539     S.D. =  .1663     C.S. =  .7400
```

	GUMBEL I		LOGNORMAL		THREE PARAMETER LOGNORMAL		LOG PEARSON III MAX. LIKELIHOOD		LOG PEARSON III MOMENTS	
RETURN PERIOD	FLOOD ESTIMATE	ST. ERROR PERCENT	FLOOD ESTIMATE	ST.ERROR PERCENT	FLOOD ESTIMATE	ST. ERROR PERCENT	FLOOD ESTIMATE	ST. ERROR PERCENT	FLOOD ESTIMATE	ST. ERROR PERCENT
1.005	49600.0		45200.0		50500.0		50900.0		48400.0	
1.050	54800.0		52900.0		54900.0		55200.0		54100.0	
1.250	60800.0		60600.0		60400.0		60600.0		60400.0	
2.000	68700.0		69800.0		68500.0		68400.0		69000.0	
5.000	79300.0	5.50	80500.0	5.08	80100.0	6.13	79600.0	5.92	80100.0	5.68
10.000	86400.0	6.48	86700.0	5.89	88000.0	8.01	87200.0	7.74	87300.0	7.18
20.000	93100.0	7.36	92200.0	6.69	95700.0	10.30	94600.0	9.95	94000.0	9.29
50.000	102000.0	8.37	98800.0	7.69	106000.0	13.80	105000.0	13.20	103000.0	12.70
100.000	108000.0	9.03	103000.0	8.40	114000.0	16.60	112000.0	15.90	109000.0	15.50
200.000	115000.0	9.63	108000.0	9.06	122000.0	19.50	120000.0	18.70	116000.0	18.50
500.000	124000.0	10.30	114000.0	9.90	133000.0	23.40	131000.0	22.60	124000.0	22.70

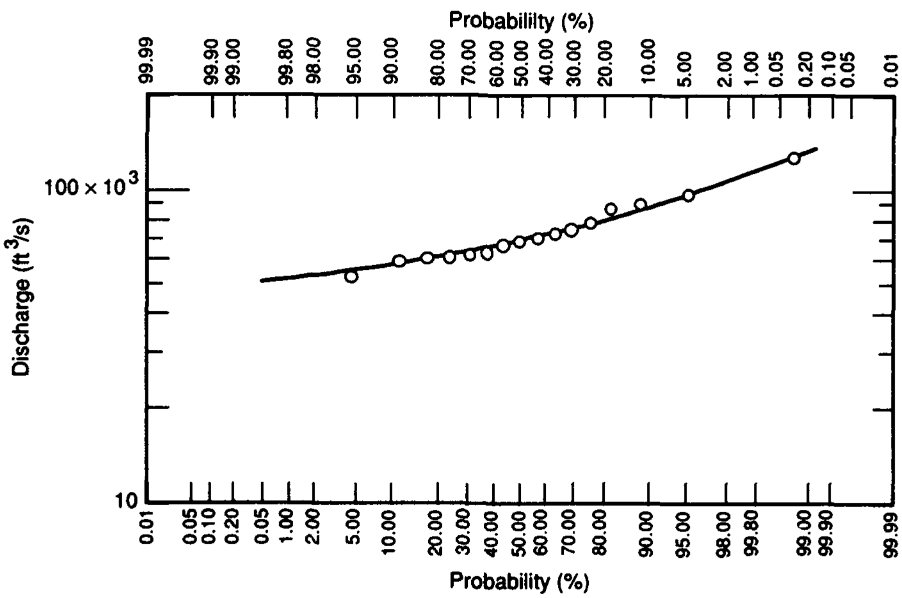


Figure A1. Plot of results from flood frequency analyses.

MAP SHEET 16-5

PERIOD 38-48

Location Number	Erosion Area m^2	Location	Location Number	Deposition Area m^2	Location
150	37,600	Island	175	2,300	Right Bank
151	3,600	Island	176	9,600	Right Bank
152	1,200	Island	177	7,700	Island
153	12,900	Island	178	12,800	Island
154	7,000	Island	179	5,900	Island
155	1,500	Right Bank	180	3,900	Left Bank
156	1,700	Right Bank			
157	1,900	Right Bank			
158	19,800	Right Bank		11,900	Total Right Bank
159	57,300	Right Bank		3,900	Total Left Bank
160	6,600	Island		26,400	Total Islands
161	2,900	Right Bank			
162	1,700	Island			
163	19,800	Island			
164	7,600	Island			
165	27,400	Left Bank			
166	12,000	Left Bank			
167	14,700	Left Bank			
168	3,400	Left Bank			
169	5,000	Island			
170	700	Island			
171	10,500	Island			
172	4,200	Island			
173	3,100	Island			
174	6,300	Island			
185	1,400	Island			
186	7,400	Island			
187	3,300	Island			
188	1,000	Island			
189	1,800	Island			
190	1,700	Right Bank			
191	2,500	Right Bank			
	89,300	Total Right Bank			
	57,500	Total Left Bank			
	142,700	Total Islands			

PERIOD 48-61

Location Number	Erosion Area m^2	Location	Location Number	Deposition Area m^2	Location
1	5,900	Right Bank	24	9,300	Island
2	7,600	Right Bank	25	8,700	Left Bank
3	63,600	Left Bank	26	4,200	Island
4	8,700	Island	27	21,200	Island
5	34,400	Island	28	4,700	Island
6	110,600	Right Bank	29	3,900	Island
7	20,700	Right Bank	30	4,800	Island
8	4,400	Island	31	15,500	Island
9	8,800	Island	32	9,500	Island
10	29,500	Island	33	11,200	Island
11	4,700	Right Bank	34	17,600	Left Bank
12	2,600	Island	35	19,600	Left Bank
13	9,200	Island	36	76,100	Left Bank
14	4,700	Island	37	92,000	Left Bank
15	37,300	Left Bank	38	2,000	Island
16	3,700	Left Bank	39	6,700	Island
17	6,500	Left Bank			

MAP SHEET 16-5 (CONT.)

PERIOD 48-61

Location Number	Erosion Area m^2	Location	Location Number	Deposition Area m^2	Location
18	2,800	Island			
19	2,100	Island		214,000	Total Left Bank
20	1,600	Island		93,000	Total Islands
21	2,400	Island			
22	7,700	Island			
23	4,900	Island			
	149,500	Total Right Bank			
	111,100	Total Left Bank			
	123,800	Total Islands			

PERIOD 61-70

Location Number	Erosion Area m^2	Location	Location Number	Deposition Area m^2	Location
43	3,500	Island	58	7,000	Right Bank
44	3,400	Island	59	20,500	Island
45	24,500	Left Bank	60	13,800	Island
46	32,400	Right Bank	61	15,600	Island
47	10,300	Island	62	27,800	Island
48	48,800	Right Bank	63	4,700	Left Bank
49	12,800	Island	64	75,800	Island
50	2,700	Right Bank	65	10,200	Island
51	20,400	Island	66	209,900	Island
52	15,000	Island	67	21,700	Island
53	3,400	Left Bank	68	36,700	Left Bank
54	5,200	Left Bank	69	71,800	Island
55	3,500	Island	70	23,200	Island
			71	7,900	Island
			72	3,800	Island
	83,900	Total Right Bank			
	33,100	Total Left Bank			
	68,900	Total Islands			
				7,000	Total Right Bank
				41,400	Total Left Bank
				502,000	Total Islands

PERIOD 70-74

Location Number	Erosion Area m^2	Location	Location Number	Deposition Area m^2	Location
76	15,000	Left Bank	88	6,000	Left Bank
77	30,400	Right Bank	89	3,500	Right Bank
78	13,500	Island	90	4,500	Right Bank
79	14,000	Right Bank	91	38,600	Island
80	11,800	Island	92	2,700	Island
81	10,900	Island			
82	5,300	Island		8,000	Total Right Bank
63	4,500	Island		6,000	Total Left Bank
84	18,700	Left Bank		41,300	Total Islands
	44,400	Total Right Bank			
	33,700	Total Left Bank			
	46,000	Total Islands			

MAP SHEET 16-5 (CONT.)

PERIOD 74-76

Location Number	Erosion Area m^2	Location	Location Number	Deposition Area m^2	Location
96	5,300	Left Bank	102	10,000	Island
97	4,700	Right Bank	103	4,100	Island
98	6,200	Right Bank			
99	12,400	Left Bank			
				14,100	Total Islands
	10,900	Total Right Bank			
	17,700	Total Left Bank			

PERIOD 76-78

Location Number	Erosion Area m^2	Location	Location Number	Deposition Area m^2	Location
106	8,300	Right Bank		None Measured	
107	4,100	Island			
108	10,800	Right Bank			
109	3,600	Right Bank			
110	4,100	Island			
111	7,200	Island			
112	5,700	Left Bank			
	22,700	Total Right Bank			
	5,700	Total Left Bank			
	15,400	Total Islands			

PERIOD 78-79

Location Number	Erosion Area m^2	Location	Location Number	Deposition Area m^2	Location
117	4,100	Island		None Measured	
118	3,600	Island			
119	2,700	Island			
	10,400	Total Islands			

PERIOD 79-80

Location Number	Erosion Area m^2	Location	Location Number	Deposition Area m^2	Location
124	17,700	Island			
125	8,800	Island		None Measured	
126	3,200	Left Bank			
127	3,600	Left Bank			
210	5,400	Island			
211	7,100	Left Bank			
212	7,800	Island			
	13,900	Total Left Bank			
	39,700	Total Islands			

MAP SHEET 16-5 (CONT.)
PERIOD 80-82

Location Number	Erosion Area m²	Location	Location Number	Deposition Area m²	Location
220	4,900	Left Bank		None Measured	
221	28,800	Left Bank			
222	23,000	Island			
223	2,300	Left Bank			
224	4,800	Left Bank			
225	10,600	Left Bank			
226	4,600	Left Bank			
227	2,800	Island			
228	15,200	Island			
229	2,000	Island			
230	11,300	Island			
	56,000	Total Left Bank			
	54,300	Total Islands			

MAP SHEET 16-7
PERIOD 38-48

Location Number	Erosion Area m²	Location	Location Number	Deposition Area m²	Location
150	37,100	Right Bank	180	4,000	Island
151	49,000	Right Bank	181	4,400	Island
152	31,500	Right Bank	182	1,700	Island
153	11,400	Left Bank	183	3,600	Island
154	25,100	Left Bank	184	800	Island
155	3,600	Island	185	5,000	Island
156	800	Left Bank			
157	5,000	Island			
158	2,700	Island		19,500	Total Islands
159	30,700	Island			
161	1,500	Island			
162	6,000	Island			
163	3,200	Left Bank			
164	2,500	Left Bank			
165	2,900	Left Bank			
166	4,000	Left Bank			
167	1,600	Right Bank			
	119,200	Total Right Bank			
	49,900	Total Left Bank			
	49,500	Total Islands			

PERIOD 48-61

Location Number	Erosion Area m²	Location	Location Number	Deposition Area m²	Location
104	5,900	Right Bank	129	9,300	Island
105	1,900	Left Bank	130	4,200	Island
106	1,400	Left Bank	131	2,400	Island
107	5,700	Left Bank	132	3,500	Island
108	4,500	Left Bank	133	22,900	Island
109	10,300	Left Bank	134	2,200	Island
110	6,000	Left Bank	135	7,700	Island
111	4,100	Island			
112	21,800	Island			

MAP SHEET 16-7 (CONT.)

PERIOD 48-61

Location Number	Erosion Area m^2	Location	Location Number	Deposition Area m^2	Location
113	22,600	Island		42,900	Total Islands
114	9,800	Island			
115	15,500	Island			
116	6,800	Island			
117	1,600	Island			
118	2,000	Island			
119	2,400	Island			
120	77,000	Right Bank			
121	3,500	Right Bank			
122	2,500	Right Bank			
123	800	Right Bank			
124	32,800	Right Bank			
125	2,100	Left Bank			
126	1,300	Island			
	116,600	Total Right Rank			
	31,900	Total Left Bank			
	87,900	Total Islands			

PERIOD 61-70

Location Number	Erosion Area m^2	Location	Location Number	Deposition Area m^2	Location
1	6,600	Island	21	14,800	Island
2	7,600	Right Bank	22	3,500	Island
3	2,400	Island	23	12,400	Island
4	3,800	Island	24	4,400	Island
5	23,300	Left Bank	25	29,400	Island
6	23,600	Island	26	92,500	Left Bank
7	11,900	Left Bank	27	84,600	Left Bank
8	8,600	Island	28	5,800	Island
9	34,500	Left Bank	29	3,500	Left Bank
10	10,700	Island	30	5,000	Left Bank
11	8,500	Island			
12	5,300	Left Bank			
13	11,200	Island		185,600	Total Left Bank
14	5,800	Island		70,300	Total Islands
15	21,300	Right Bank			
16	67,300	Right Bank			
17	6,200	Left Bank			
18	1,500	Right Bank			
	97,700	Total Right Bank			
	81,200	Total Left Bank			
	81,200	Total Islands			

PERIOD 70-74

Location Number	Erosion Area m^2	Location	Location Number	Deposition Area m^2	Location
34	21,400	Right Bank	45	16,100	Island
35	16,500	Left Bank	46	1,800	Island
36	51,200	Island	47	2,500	Island
37	12,300	Left Bank			
38	2,800	Island			
39	6,200	Right Bank		20,400	Total Islands

MAP SHEET 16-7 (CONT.)

PERIOD 70-74 (CONT.)

Location Number	Erosion Area m^2	Location	Location Number	Deposition Area m^2	Location
40	14,100	Right Bank			
41	9,100	Right Bank			
	50,800	Total Right Bank			
	28,800	Total Left Bank			
	54,000	Total Islands			

PERIOD 74-76

Location Number	Erosion Area m^2	Location	Location Number	Deposition Area m^2	Location
51	8,500	Island	59	1,900	Island
52	4,700	Island	60	10,200	Island
53	8,600	Island	61	6,300	Island
54	5,200	Island	62	9,800	Right Bank
55	7,400	Left Bank			
56	8,600	Island			
				9,800	Total Right Bank
				18,400	Total Islands
	7,400	Total Left Bank			
	35,600	Total Islands			

PERIOD 76-78

Location Number	Erosion Area m^2	Location	Location Number	Deposition Area m^2	Location
66	9,800	Island	73	3,100	Island
67	4,900	Island	74	3,700	Island
68	20,600	Island	75	4,000	Island
69	20,700	Right Bank	76	27,200	Island
		20,700 Total Right Bank			38,000
Total Islands					
	35,300	Total Islands			

PERIOD 78-79

Location Number	Erosion Area m^2	Location	Location Number	Deposition Area m^2	Location
83	7,400	Island	89	26,700	Right Bank
84	10,600	Island	90	16,000	Island
85	20,200	Right Bank	91	11,000	Island
			92	14,700	Island
			93	12,100	Island
	20,200	Total Right Bank	94	6,000	Island
	18,000	Total Islands	95	15,400	Island
			96	3,700	Island
			97	11,800	Island
				26,700	Total Right Bank
				90,700	Total Islands

MAP SHEET 16-7 (CONT.)

PERIOD 79-80

Location Number	Erosion Area m^2	Location	Location Number	Deposition Area m^2	Location
100	8,500	Right Bank			
101	24,800	Island		None Measured	
	8,500	Total Right Bank			
	24,800	Total Islands			

PERIOD 80-82

Location Number	Erosion Area m^2	Location	Location Number	Deposition Area m^2	Location
200	13,800	Left Bank			
201	15,600	Left Bank		None Measured	
202	13,800	Left Bank			
203	2,700	Island			
204	4,500	Island			
205	12,100	Island			
	43,200	Total Left Bank			
	19,300	Total Islands			

MAP SHEET 16-9

Period 38-48

Location Number	Erosion Area m^2	Location	Location Number	Deposition Area m^2	Location
201	4,800	Right Bank	250	1,800	Island
202	20,400	Right Bank	251	1,200	Island
203	25,100	Right Bank	252	1,700	Island
204	2,500	Island	253	11,800	Island
205	400	Island	254	700	Island
206	3,800	Island	255	100	Island
207	13,500	Island	256	2,000	Island
208	11,800	Island	257	300	Island
209	24,800	Island	258	2,800	Island
210	600	Island	259	2,400	Island
211	2,700	Island	260	800	Island
212	1,500	Left Bank	261	6,700	Island
213	16,500	Island	262	400	Island
			263	200	Island
			264	400	Island
	50,300	Total Rigth Bank			
	1,500	Total Left Bank			
	76,600	Total Islands		33,300	Total Islands

Period 48-61

Location Number	Erosion Area m^2	Location	Location Number	Deposition Area m^2	Location
1	4,800	Right Bank	28	7,700	Island
2	81,800	Right Bank	29	4,200	Island
3	59,900	Island	30	4,900	Island
4	1,500	Island	31	4,900	Island
5	1,500	Island	32	4,800	Island
6	1,800	Island	33	7,500	Island
7	1,600	Island	34	9,100	Island

MAP SHEET 16-9 (CONT'D)

Period 48-61 (CONT'D)

Location Number	Erosion Area m^2	Location	Location Number	Deposition Area m^2	Location
8	1,100	Island	35	6,000	Right Bank
9	2,400	Island	36	2,900	Left Bank
10	7,400	Island	37	1,900	Island
11	15,100	Right Bank			
12	1,800	Right Bank			
13	5,600	Island		6,000	Total Right Bank
14	10,200	Island		2,900	Total Left Bank
15	155,500	Left Bank		45,000	Total Islands
16	7,600	Island			
17	10,400	Island			
18	4,800	Right Bank			
19	13,000	Island			
20	48,800	Right Bank			
21	9,300	Island			
22	37,000	Island			
23	5,300	Island			
24	3,100	Island			
	157,100	Total Right Bank			
	155,500	Total Left Bank			
	178,700	Total Islands			

Period 61-70

Location Number	Erosion Area m^2	Location	Location Number	Deposition Area m^2	Location
41	164,900	Left Bank	63	7,800	Island
59	2,200	Island	64	5,200	Island
43	3,900	Island	65	56,500	Island
44	2,700	Island	66	26,200	Left Bank
45	23,500	Island	67	5,400	Island
46	7,200	Right Bank	68	8,700	Left Bank
47	13,700	Right Bank	69	4,200	Island
48	4,800	Island	70	3,300	Island
49	72,200	Left Bank	71	2,500	Island
50	23,100	Island	72	24,200	Island
51	6,500	Right Bank			
52	4,000	Island			
53	4,200	Island		34,900	Total Left Bank
54	9,100	Island		109,100	Total Islands
55	2,300	Island			
56	8,100	Island			
57	5,000	Island			
58	2,800	Island			
59	1,800	Left Bank			
	192,300	Total Right Bank			
	74,000	Total Left Bank			
	95,700	Total Islands			

MAP SHEET 16-9 (CONT.)

PERIOD 70-74

Location Number	Erosion Area m^2	Location	Location Number	Deposition Area m^2	Location
76	7,700	Right Bank	90	3,300	Island
77	8,000	Right Bank			
78	7,600	Right Bank			
79	5,800	Island		3,300	Total Islands
80	6,800	Right Bank			
81	14,400	Left Bank			
82	2,900	Right Bank			
83	5,800	Right Bank			
84	2,300	Island			
85	3,600	Island			
86	2,900	Island			
87	2,300	Island			
	38,800	Total Right Bank			
	14,400	Total Left Bank			
	16,900	Total Islands			

PERIOD 74-76

Location Number	Erosion Area m^2	Location	Location Number	Deposition Area m^2	Location
94	14,000	Right Bank			
95	3,700	Right Bank		None Measured	
96	4,000	Right Bank			
97	5,000	Island			
	21,700	Total Right Bank			
	5,000	Total Islands			

PERIOD 76-78

Location Number	Erosion Area m^2	Location	Location Number	Deposition Area m^2	Location
102	4,900	Right Bank	107	1,800	Island
103	11,700	Right Bank			
108	8,600	Left Bank			
104	8,800	Island			
				8,600	Total Left Bank
	16,600	Total Right Bank		1,800	Total Island
	8,800	Total Island			

MAP SHEET 16-9

PERIOD 78-79

Location Number	Erosion Area m^2	Location	Location Number	Deposition Area m^2	Location
111	4,800	Right Bank	116	2,300	Island
112	3,600	Island	117	4,700	Island
			118	3,200	Island
			119	4,800	Island
	4,800	Total Right Bank	120	13,000	Island
	3,600	Total Islands	121	23,400	Island
			122	4,800	Island
			123	3,800	Island

MAP SHEET 16-9 (CONT'D)

PERIOD 78-79 (CONT'D)

Location Number	Erosion Area m^2	Location	Location Number	Deposition Area m^2	Location
			124	20,500	Island
			125	62,900	Left Bank
			126	14,700	Island
			127	20,000	Island
			128	3,400	Island
			129	12,700	Island
			130	6,100	Island
			131	19,400	Island
				62,900	Total Left Bank
				156,800	Total Islands

PERIOD 79-80

Location Number	Erosion Area m^2	Location	Location Number	Deposition Area m^2	Location
134	9,100	Right Bank			
260	3,200	Island		None Measured	
	9,100	Total Right Bank			
	3,200	Total Islands			

PERIOD 80-8

Location Number	Erosion Area m^2	Location	Location Number	Deposition Area m^2	Location
240	1,500	Right Bank			
241	1,800	Right Bank		None Measured	
242	1,700	Island			
243	4,500	Right Bank			
244	2,000	Island			
245	2,600	Island			
246	1,300	Island			
	7,800	Total Right Bank			
	7,600	Total Islands			

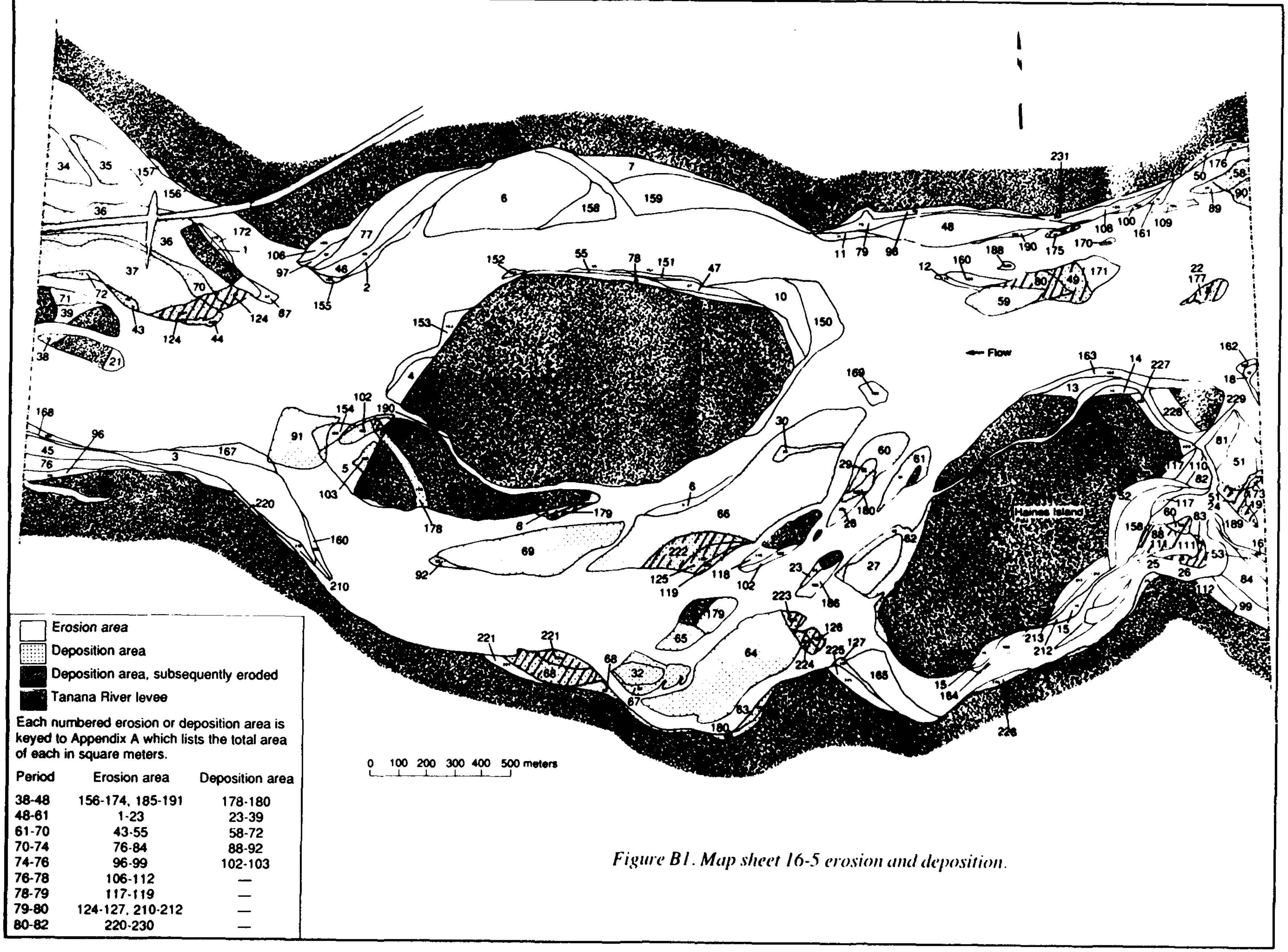
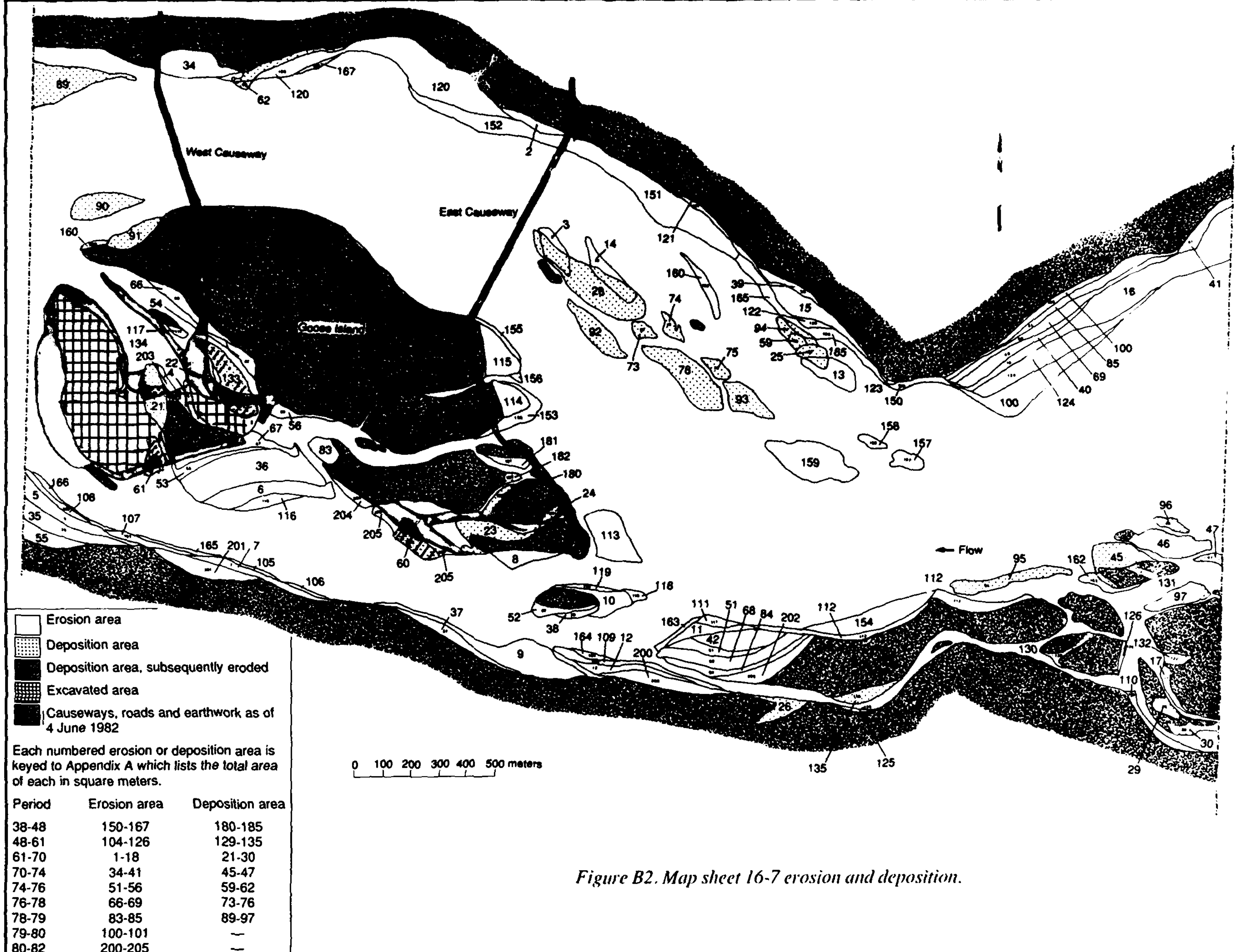
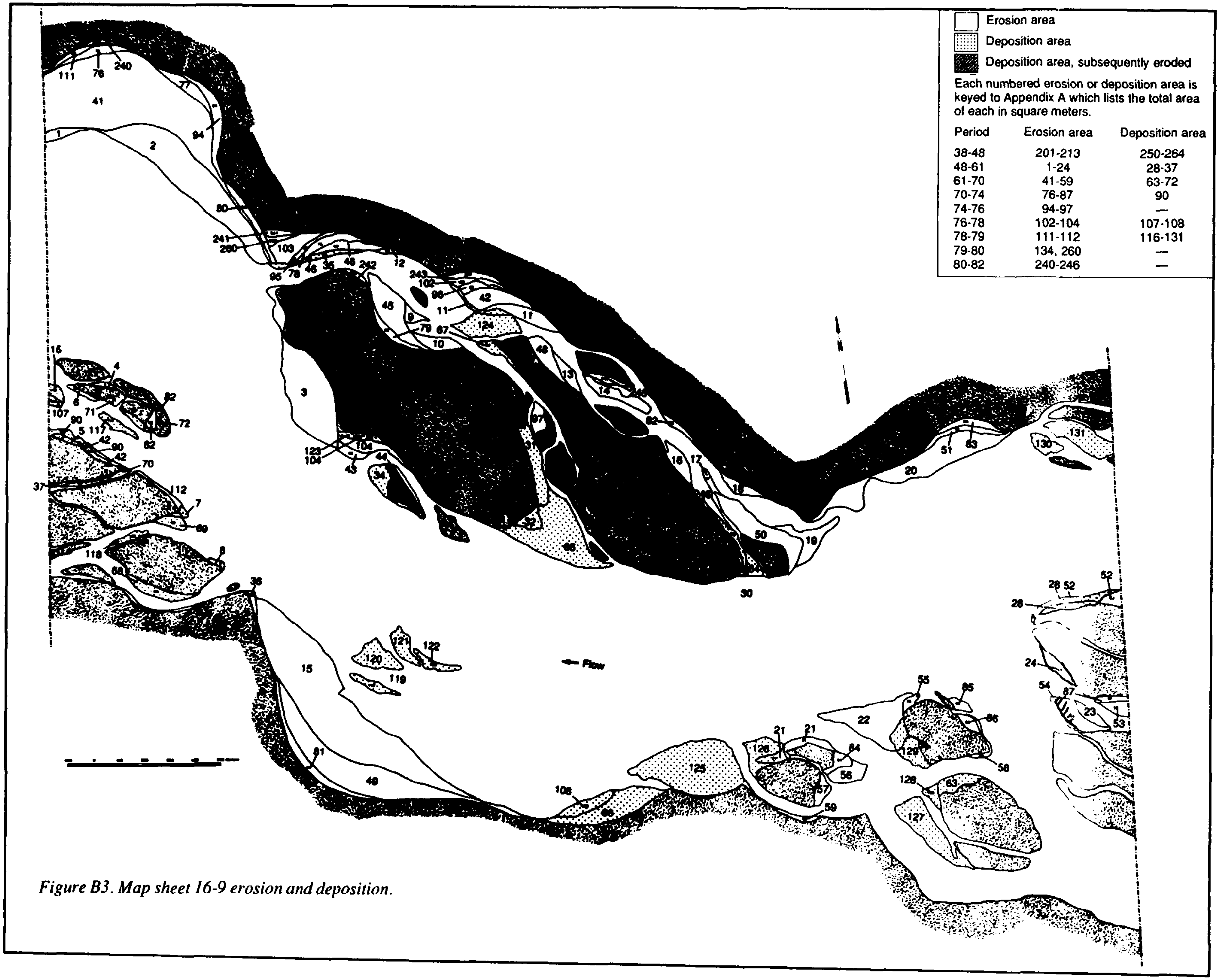


Figure B1. Map sheet 16-5 erosion and deposition.



Period	Erosion area	Deposition area
38-48	150-167	180-185
48-61	104-126	129-135
61-70	1-18	21-30
70-74	34-41	45-47
74-76	51-56	59-62
76-78	66-69	73-76
78-79	83-85	89-97
79-80	100-101	—
80-82	200-205	—

Figure B2. Map sheet 16-7 erosion and deposition.



Period	Erosion area	Deposition area
38-48	201-213	250-264
48-61	1-24	28-37
61-70	41-59	63-72
70-74	76-87	90
74-76	94-97	—
76-78	102-104	107-108
78-79	111-112	116-131
79-80	134, 260	—
80-82	240-246	—

Figure B3. Map sheet 16-9 erosion and deposition.

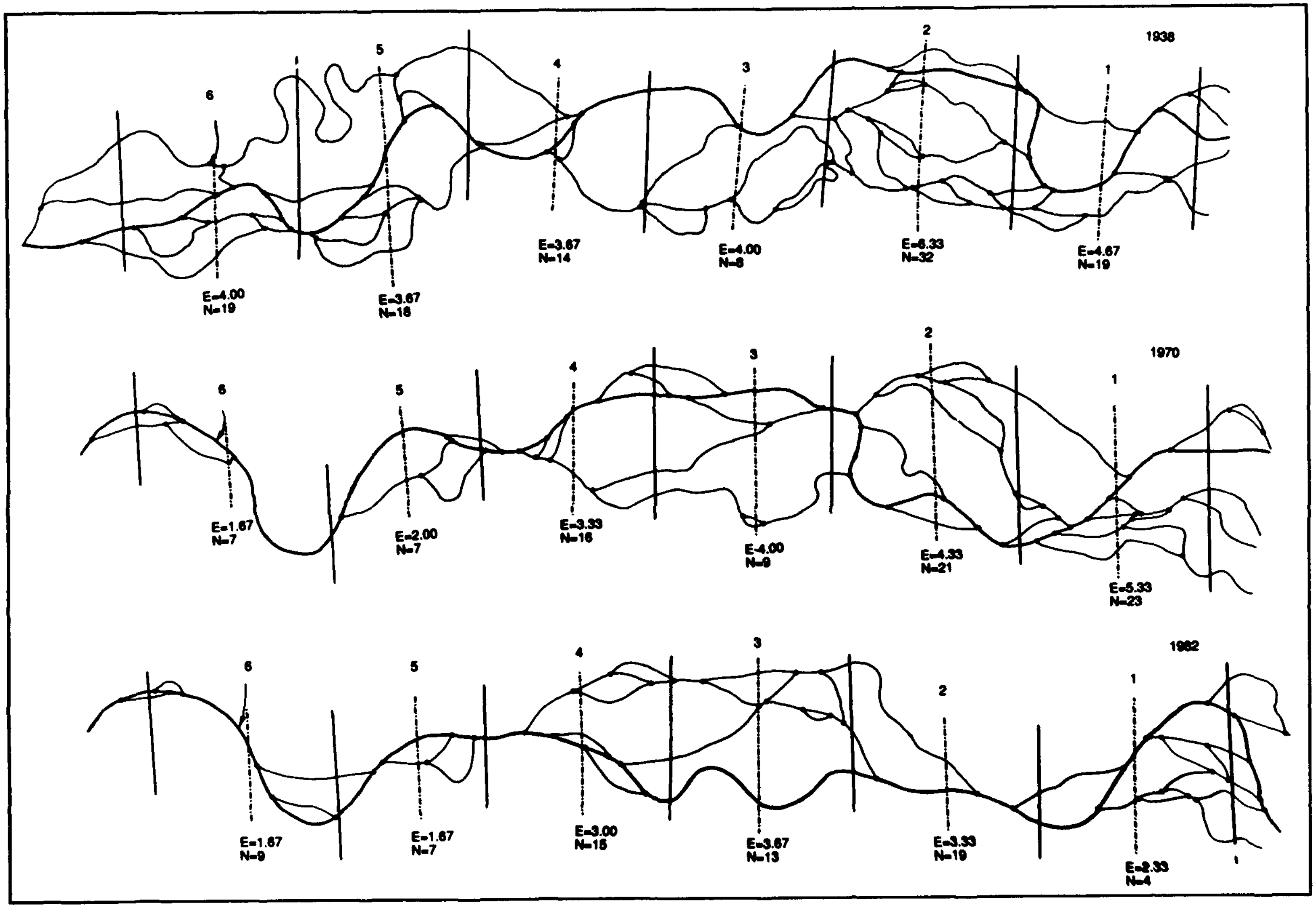


Figure B4. Topologic analysis, Tanana River 1938, 1970, and 1982.

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13. ABSTRACT (*Maximum 200 words*)

Long-term bank erosion rates and channel changes in a 14-km stretch of the Tanana River centered on Goose Island were documented using historical aerial photography from 1938 through 1982. The construction effects of a causeway partially blocking the river and the time required to return to equilibrium after construction were studied. Erosion, averaged over the entire study reach, was not significantly different following causeway construction compared to that prior to construction. Significant short-term increases in localized erosion rates during post- vs pre-construction time periods were documented in south channels and islands downstream of the causeway. Deposition upstream of the river constriction formed by the causeway was dramatic. The Tanana River returned to near equilibrium by 1980, five years after the construction of the causeway, with some effects continuing in 1982. Due to additional in-river construction downstream of the study area in 1981, the separate effects from the causeway could not be monitored beyond 1982.

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